1-29-80

REPORT NO. NADC-79141-60

V/STOL EQUIVALENT SYSTEMS ANALYSIS

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May 1980

Final Report for Period 27 August 1979 - 27 May 1980

800455A

Approved for Public Release; Distribution Unlimited

Prepared for

United States Navy
Naval Air Development Center
Warminster, Pennsylvania 18974

19970610 075

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: NADC-79141-60	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): V/STOL EQUIVALENT SYSTEMS ANALYSIS	5. TYPE OF REPORT & PERIOD COVERED: Final Report for Period 27 August 1979-27 May 1980
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): C. G. CARPENTER, J. HODGKINSON	8. CONTRACT OR GRANT NUMBER(s): N62269-79-C-0700
9. PERFORMING ORGANIZATION NAME AND ADDRESS: McDonnell Aircraft Company, McDonnell Douglas Corporation, P.O. Box 516, St. Louis, Missouri 63166	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: PE62241N, WF41400
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Air Development Center, Code 6053, Warminster, PA 18974	12. REPORT DATE: March 1980
	13. NUMBER OF PAGES: 209
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

19970610 075

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

V/STOL Equivalent Systems, Hover and Low Speed Flight, V/STOL Flying Qualities Fixed Base Manned Simulation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A fixed base manned V/STOL handling qualities simulation was performed to answer questions concerning: (a) the pilot's frequency range of interest, (b) the maximum allowable mismatch between high order systems and their low order equivalents, (c) acceptability of high order appearing responses and (d) the piloting effects of phase lag at the natural frequency versus time delay. Various high or low frequency terms were added to low order attitude systems. Pilot ratings and comments showed that the pilot's frequency range of interest was .5-4.0 rad/sec; the amount of mismatch allowed was dependent on the type

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of high order dynamics added and the match frequency range; pilots did not accept high order appearing dynamics and; time delay is a better correlating parameter than phase lag at the configuration natural frequency. Equivalent systems analysis established criteria for the different flying qualities levels in terms of equivalent parameters.

FOREWORD

This study was conducted under Contract No. N62269-79-C-0700 to the Naval Air Development Center, and was monitored by Mr. John W. Clark, Jr., Flight Dynamics Branch (Code 6053).

Mr. Roger H. Hoh of Systems Technology Incorporated (STI) and Mr. Rogers E. Smith of Calspan made significant contributions to the study. Mr. Smith also acted as an evaluation pilot.

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LIST OF SYMBOLS

F_s	Stick Force, N
HOS	High Order System
K	Command Gain, rad/sec^2/cm
LOS	Low Order System
m	Aircraft Mass, kg
n	Number of Frequencies
p	Body Angular Roll Rate, rad/sec
q	Body Angular Pitch Rate, rad/sec
s	Laplace Operator, sec^{-1}
u	Body-Axis Velocity, X-Direction, m/sec
v	Body-Axis Velocity, Y-Direction, m/sec
Y_v	$(\partial Y/\partial v)/m$, sec^{-1}
δ_{PED}	Rudder Pedal Displacement, cm
δ_{ST}	Stick Displacement, cm
ζ	Damping Ratio
ζ_e	Equivalent Damping Ratio
θ	Pitch Angle, rad
λ	Root of First Order Lag
τ	Time Delay, sec
τ_e	Equivalent Time Delay, sec
ϕ	Roll Angle, rad
$\dot{\psi}$	Yaw Rate, rad/sec
ω_B	Break Frequency of Turbulence Model, rad/sec
ω_{DP}	Dipole Frequency, rad/sec
ω_e	Equivalent Frequency, rad/sec
ω_L	Lag Frequency, rad/sec
ω_n	Natural Frequency, rad/sec

I INTRODUCTION

High order mathematical models are used to simulate the response of a vertical/short takeoff and landing (V/STOL) aircraft to pilot or turbulence inputs. A recent Naval Air Development Center (NADC) contract (N62269-77-C-0278), Reference 1, categorized high order V/STOL responses in terms of low order equivalent systems. Reference 1 then used equivalent parameters to propose modifications to the V/STOL flying qualities Military Specification, MIL-F-83300. It has become imperative to determine the capability of these low order equivalent systems to adequately approximate the high order dynamics.

This present study investigated equivalent system techniques for defining V/STOL handling qualities criteria in hover and low speed flight. It addressed four questions:

1) What is an allowable mismatch between the high order system and its low order equivalent?

2) What is the pilot's frequency range of interest, in which a good match should be assured?

3) Do pilots require low-order-appearing responses in attitude, velocity and position to control inputs, and will they reject more complicated higher order responses?

4) What are the piloting effects of time delay versus the effects of phase lag?

Considerable research has been performed on the flying qualities of augmented aircraft, using the equivalent systems approach. Much equivalent systems work has been done by Systems Technology Incorporated (for example the early Navy-sponsored studies of References 2 and 3) and by McDonnell Aircraft, MCAIR (for example, References 4 and 5). These references discuss the augmented dynamics of conventional takeoff and landing (CTOL) aircraft. In fact, low order equivalent systems have emerged as the most widely accepted technique for analyzing high order CTOL dynamics. This led to proposals that the CTOL flying qualities specification, MIL-F-8785B (ASG), should be written in terms of equivalent systems (References 4 and 6). NADC and the USAF Flight Dynamics Laboratory (AFFDL) then sponsored an in-flight simulation, using the variable stability NT-33 aircraft, to validate the CTOL equivalent systems concept. The simulation is described in Reference 7 and initial analytical results are presented in Reference 8.

This NT-33 study produced a surprising result. It was discovered that the pilots were relatively insensitive to large mismatches between high order dynamics and their low order

equivalents. For example, in performing analytical matching of CTOL dynamics, a mismatch function had been defined as

$$\frac{20}{n} \sum (\text{Gain}_{HOS} - \text{Gain}_{LOS})^2 + .02\ (\text{Phase}_{HOS} - \text{Phase}_{LOS})^2$$

where the summation is performed over n frequencies equispaced on a Bode plot. A value of 10 for this mismatch had been arbitrarily chosen as a good match based on the visual Bode match quality. In the NT-33 simulation, high order systems were evaluated together with their low order equivalents. The pilots were unable to distinguish between pairs of systems with mismatches as high as 200.

The most likely explanation for the observed insensitivity of flying qualities to mismatch is that mismatch alone is not the critical parameter. This may stem from the fact that the range of frequency and damping values for good flying qualities is large. In other words mismatch will exist between two low order systems with parameters near the extremes of the Level 1 region. The pilot comments and ratings for these two low order systems are not expected to differ much in spite of the large mismatch between them.

It therefore may be necessary to specify how mismatch is generated, by defining what type of high order effect has been added to a low order response. Theoretically, a virtually infinite number of effects can be added to a low order response. Fortunately, a relatively small number of effects are encountered in practice.

The foregoing findings led to the approach (used in the present study) of systematically augmenting low order responses with high order effects and determining the flying qualities rating on the simulator. By adding augmentation progressively to increase mismatch, a mismatch threshold can be established for a given type of augmentation. This threshold is the mismatch level at which the rating just begins to degrade. An analyst then has a guideline for evaluating his augmented dynamics by using an equivalent system which should fall within the mismatch threshold. Alternatively, the analyst can increase the order of the equivalent system by adding a term of the same type added in this present study. In this case the mismatch will decrease and the parameters of the added term also become available for correlation. This latter approach has the disadvantage of increasing the dimension of the analyst's problem, but the advantage of reducing the mismatch. Both approaches were used in this present study.

The four questions on equivalence were therefore tackled by simulation of two nominal attitude control systems with various amounts of added low and high frequency dynamics. Section II describes the simulator and presents the justification for the parameter values chosen. Section III describes the results and Section IV presents a summary and conclusions. Section V gives recommendations for further work. The experimental data are documented fully in the Appendices.

II DESCRIPTION OF THE SIMULATION

1. Simulator and Display - The simulation was conducted in the McDonnell AV-8B fixed base simulator cockpit, shown in Figure 1. The external world display was produced by the VITAL IV three window display system (not shown in Figure 1).

The AV-8B simulator cockpit, shown in Figure 2, duplicates the actual aircraft in physical geometry, control and display layout, and function.

A minimum of cockpit instrumentation was used since the test was mainly visual. The altitude in 3.048 m (10 ft) increments was displayed by two digits on the heads-up display (HUD).

The stick force gradients used were approximately 3.07 Newtons/cm (1.75 pounds/in) in pitch control and 3.13 Newtons/cm (1.79 pounds/in) in left roll control and 4.05 Newtons/cm (2.31 pounds/in) in right roll control. A rudder force gradient of approximately 28.89 Newtons/cm (16.5 pounds/in) was used throughout. The stick deflections available were +13.716 cm (5.4 in) and -5.334 cm (-2.1 in) longitudinally and ±7.62 cm (±3.0 in) laterally. The rudder pedal travel was ±5.385 cm (±2.12 in).

The thrust control was of the throttle type.

VITAL IV is a general purpose computer-generated simulation display system. The image is generated on a digital computer with a refresh rate of 20 Hz. The high-resolution, multi-color image is displayed in virtual image form.

For the AV-8B simulator application, three VITAL display units are arranged about the front of the cockpit to provide a wide angle scene. Each display unit has a field-of-view of approximately 35° by 45°. The total field-of-view is approximately ±60° horizontally. The vertical field-of-view of the front unit is about 15° up to 20° over the nose. The side units provide a vertical field-of-view of about 5° up to 40° down. This arrangement is especially well suited for providing ground visibility for VTOL operations.

The visual display used was a twilight scene of the Minneapolis/St. Paul airport.

Figure 3 presents a "birds-eye" view of the AV-8B cockpit and the simulated VITAL IV display.

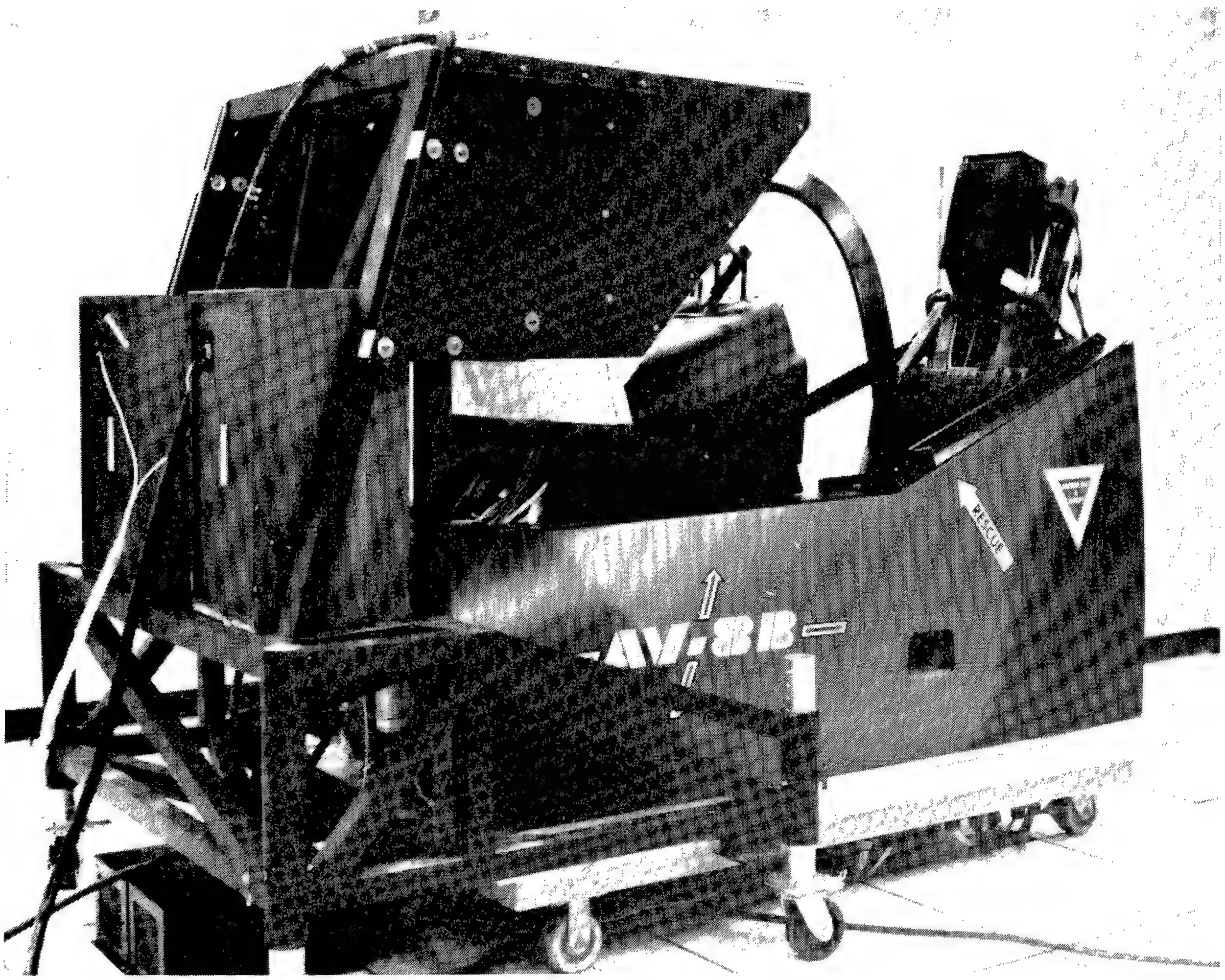

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Figure 1. AV-8B Fixed Base Simulator

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Figure 2. AV-8B Simulator Cockpit

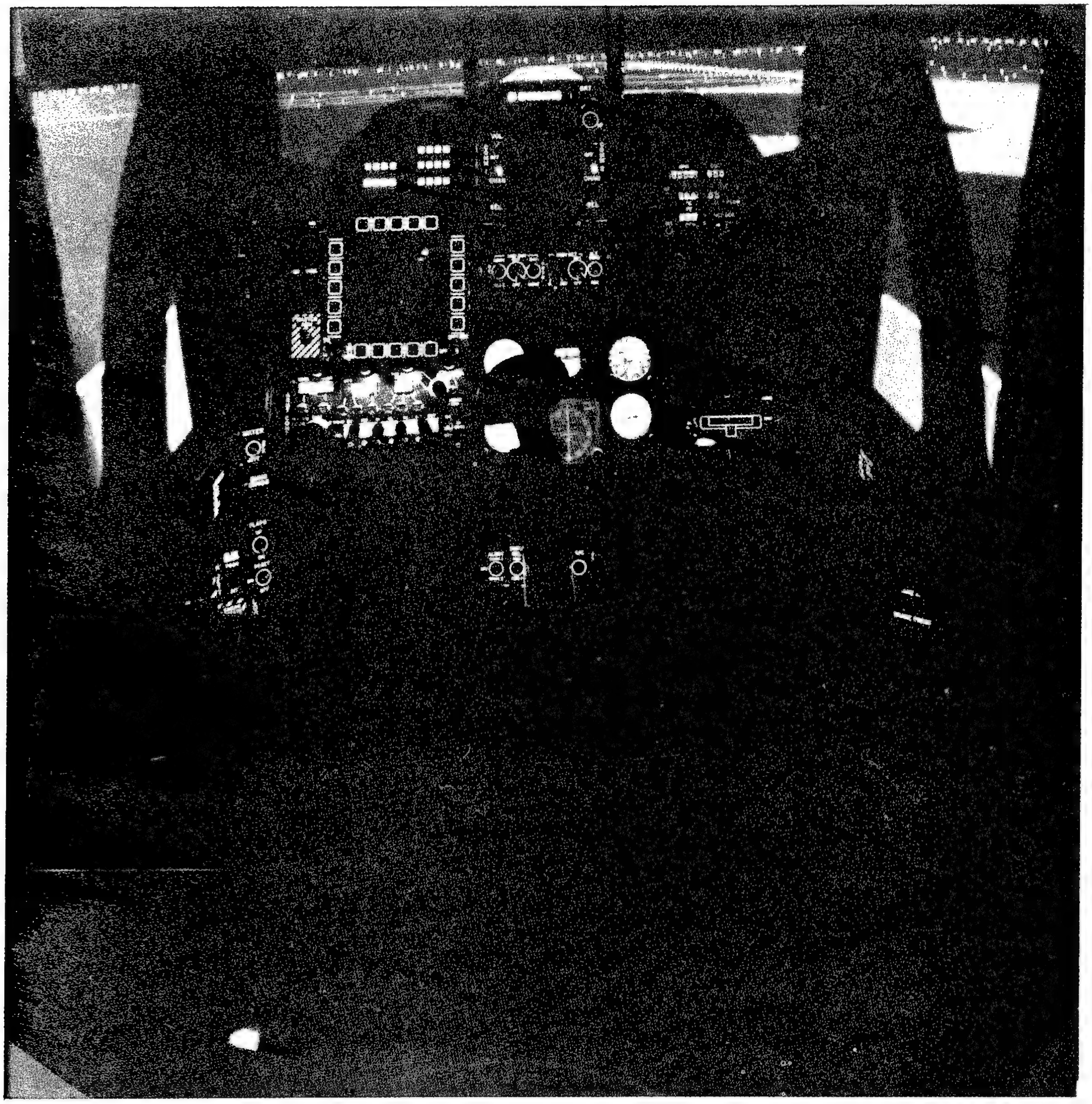


Figure 3. AV-8B Cockpit and VITAL IV Display

The following data were recorded on strip-chart recorders:

Lateral Stick Position
Longitudinal Stick Position
Rudder Pedal Position
Lateral Stick Force
Longitudinal Stick Force
Rudder Pedal Force
Throttle Position
Altitude
Roll Rate
Roll Angle
Pitch Rate
Pitch Angle
Yaw Rate
Yaw Angle
Gust Response (Directions and Velocities)
Body Angular Rates p and q
Body-Axis Velocities u and v

The following data were recorded on magnetic tape:

Roll, Pitch, Yaw and Thrust Cockpit Control Positions
Altitude
Computed Pitch, Roll and Yaw Angles
Gust Response (Directions and Velocities)
Body Angular Rates p and q

Fast Fourier analysis was used during checkout to verify the configurations.

Voice recordings were made throughout the simulation.

2. Choice of Experimental Variables

(a) Background - Figure 4 illustrates a YAV-8B pitch rate response which was used in establishing the experiment groundrules. The response is a first order lag, with added modes at high and low frequency. In any arbitrary frequency range, the total high order response can be approximated by a baseline first order lag alone, together with a mismatch caused by the added modes. Since the pilot rating for the configuration is Level 1 these mismatches due to the added nuisance modes would be negligible to the pilot.

(b) Choice of Baseline Dynamics - The YAV-8B response is a rate system generated by a rate feedback. Other system types have been proposed in which, for example, attitude and velocity feedbacks are added. Examples of these systems, depending on the mechanization, have been described as attitude, translation rate, rate command attitude hold, and translation rate position hold. Examination of all these systems is beyond the scope of this present study. Attitude command dynamics were chosen as

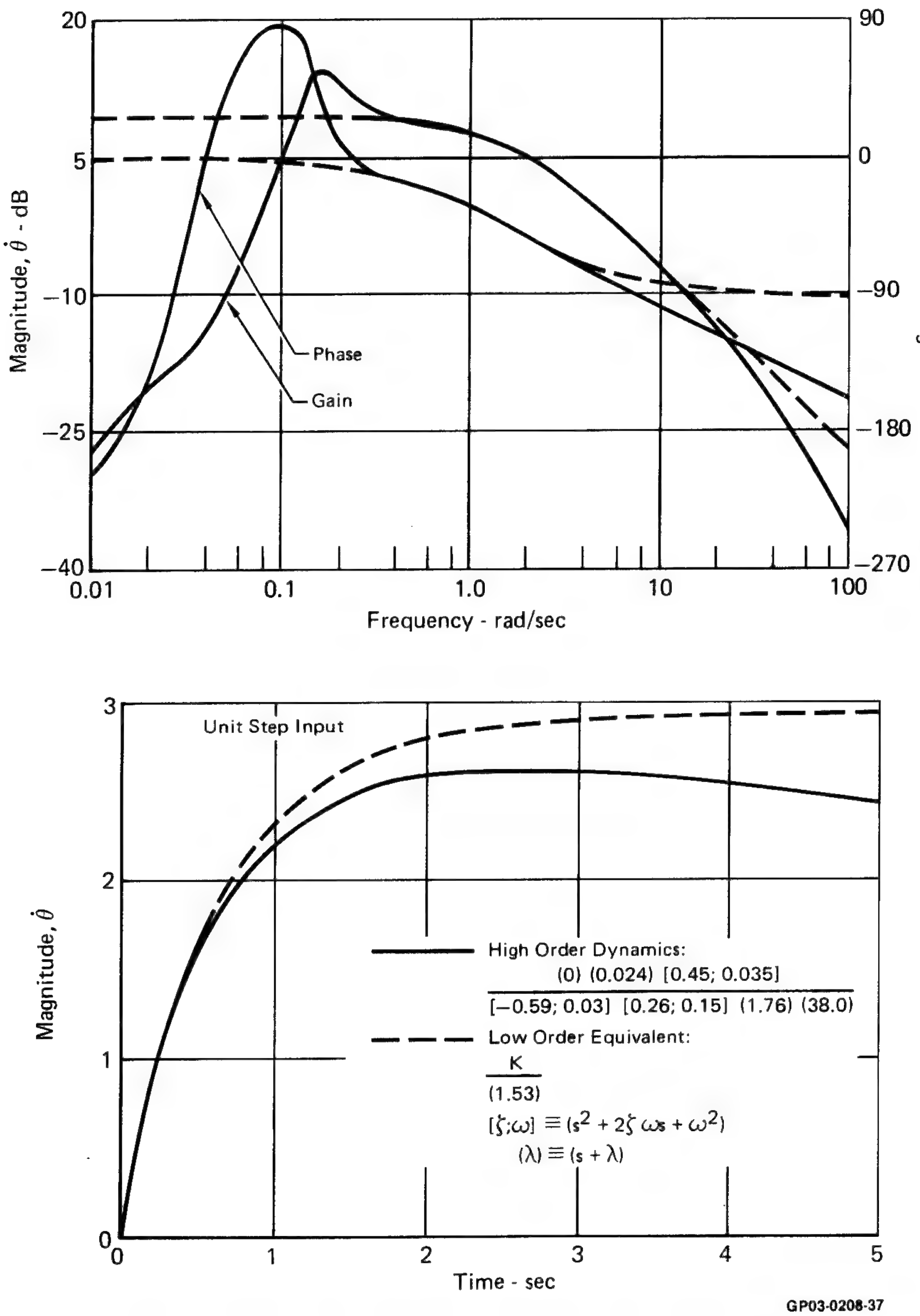
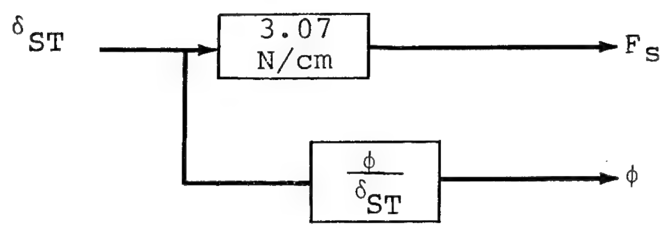


Figure 4. Comparison of High Order and Low Order Equivalent YAV-8B Normalized Pitch Dynamics

the baseline for this study since previous studies (e.g., Reference 1) have indicated this to be the nominally acceptable augmentation for operation in the Navy environment. Bank angle dynamics were chosen as a suitable axis for study. To simplify the study further, only hover and very low speed dynamics were considered.

To prevent the pilot from being influenced by the longitudinal, directional and thrust-to-throttle dynamics, these systems remained constant throughout the simulation. They were chosen after investigation into previous simulations (Reference 9, 10 and 11).

(c) Nominal Low Order Lateral Dynamics - Two baselines were defined as below.



where $\phi/\delta_{ST} = \dfrac{.708 \text{ rad/sec}^2\text{/cm}}{[.7;2.0]}$ (N1LAT)

or $\phi/\delta_{ST} = \dfrac{2.95 \text{ rad/sec}^2\text{/cm}}{[.7;5.0]}$ (N2LAT)

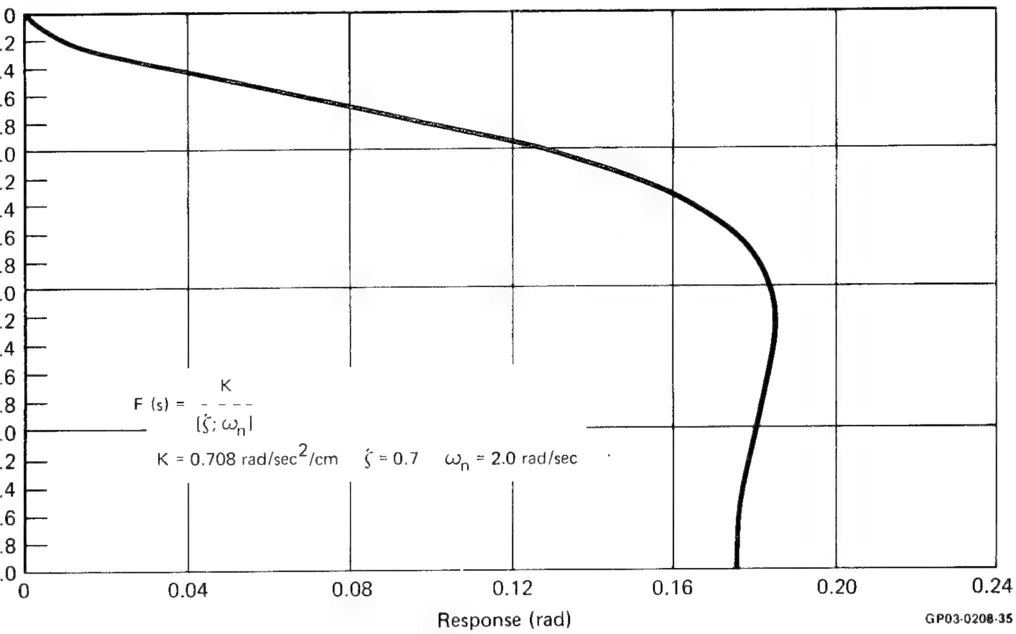
using the notation $\dfrac{K}{S^2 + 2\zeta\omega_n S + \omega_n^2} \triangleq \dfrac{K}{[\zeta;\omega_n]}$.

Time history responses to step and impulse inputs for both nominal systems are shown in Figures 5 and 6. The impulse responses confirm that the dynamics are attitude systems when compared with the criterion of Reference 1.

The nominal systems were designated N1LAT (.708/[.7;2.0]) and N2LAT (2.95/[.7;5.0] as shown. Note that the command gain values for N1LAT and N2LAT were .708 and 2.95 rad/sec^2/cm respectively. Command gains of .472 and .944 rad/sec^2/cm were used in a few cases for N1LAT.

Step Response
1 cm Input

Tabulated Response (rad)	Time (sec)
0.888178E−15	0
0.116979E−01	0.2
0.383641E−01	0.4
0.703565E−01	0.6
0.101524E+00	0.8
0.128451E+00	1.0
0.149702E+00	1.2
0.165141E+00	1.4
0.175393E+00	1.6
0.181444E+00	1.8
0.184363E+00	2.0
0.185140E+00	2.2
0.184600E+00	2.4
0.183372E+00	2.6
0.181901E+00	2.8
0.180468E+00	3.0
0.179230E+00	3.2
0.178254E+00	3.4
0.177544E+00	3.6
0.177073E+00	3.8
0.176795E+00	4.0



Impulse Response
1 cm Input

Tabulated Response (rad)	Time (sec)
0.850186E−15	0
0.105569E+00	0.2
0.153109E+00	0.4
0.161754E+00	0.6
0.147136E+00	0.8
0.120999E+00	1.0
0.914405E−01	1.2
0.635019E−01	1.4
0.398660E−01	1.6
0.215453E−01	1.8
0.847568E−02	2.0
− 0.144860E−04	2.2
− 0.468240E−02	2.4
− 0.704373E−02	2.6
− 0.743817E−02	2.8
− 0.676424E−02	3.0
− 0.556152E−02	3.2
− 0.420215E−02	3.4
− 0.291765E−02	3.6
− 0.183120E−02	3.8
− 0.989226E−03	4.0

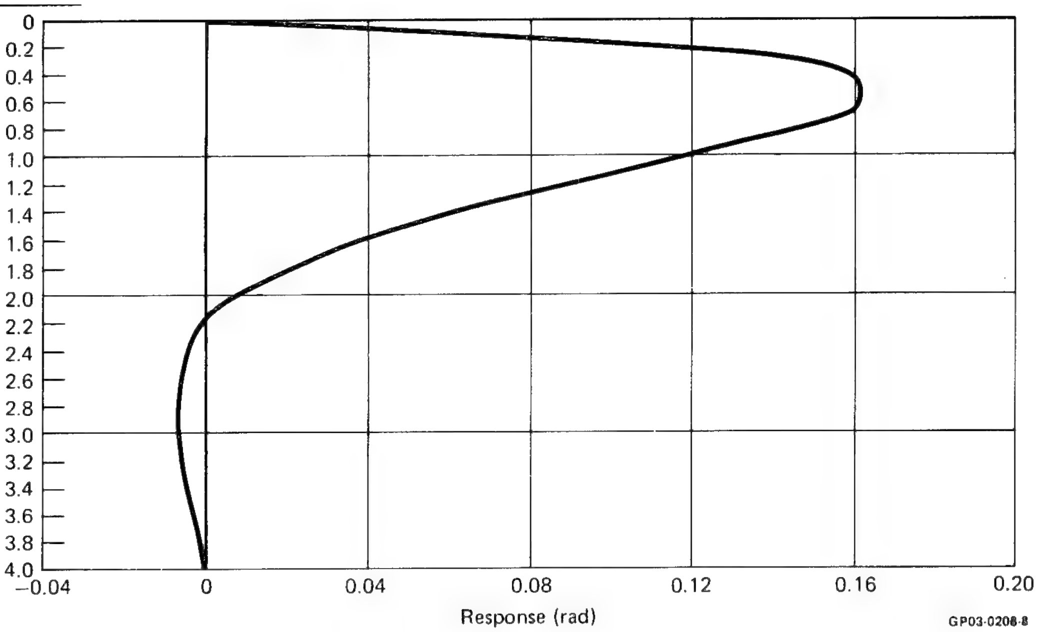
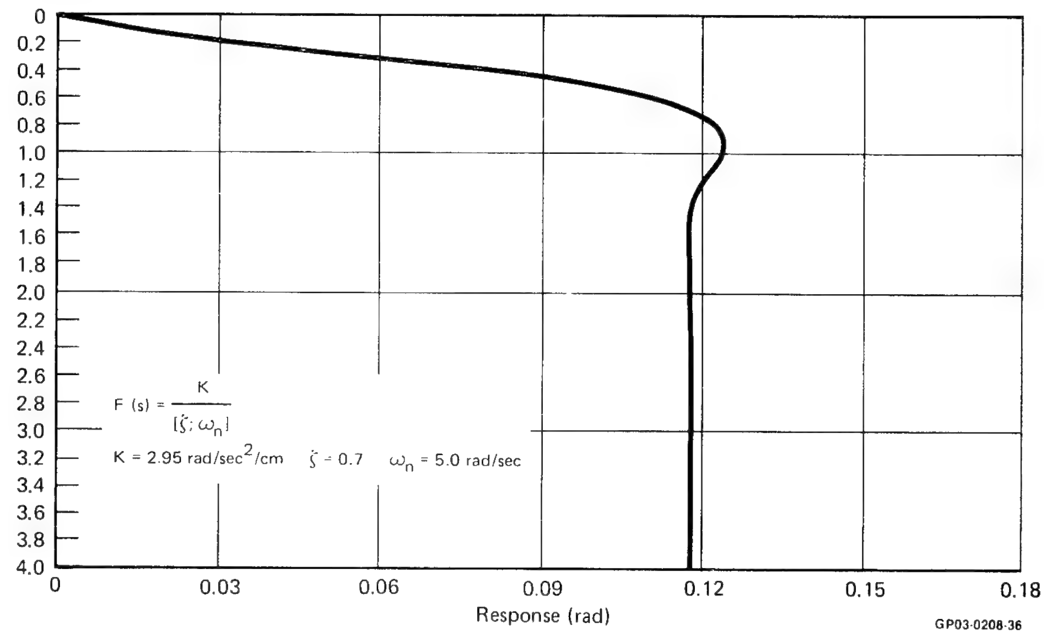


Figure 5. Lateral Dynamics, ϕ/δ_{ST}
N1LAT

Step Response
1 cm Input

Tabulated Response (rad)	Time (sec)
0.177636E−14	0
0.361016E−01	0.2
0.856341E−01	0.4
0.113906E+00	0.6
0.122908E+00	0.8
0.122693E+00	1.0
0.120312E+00	1.2
0.118578E+00	1.4
0.117863E+00	1.6
0.117755E+00	1.8
0.117850E+00	2.0
0.117948E+00	2.2
0.117998E+00	2.4
0.118011E+00	2.6
0.118009E+00	2.8
0.118004E+00	3.0
0.118001E+00	3.2
0.118000E+00	3.4
0.118000E+00	3.6
0.118000E+00	3.8
0.118000E+00	4.0



Impulse Response
1 cm Input

Tabulated Response (rad)	Time (sec)
0.141698E−14	0
0.268709E+00	0.2
0.201665E+00	0.4
0.850853E−01	0.6
0.141261E−01	0.8
− 0.103802E−01	1.0
− 0.112737E−01	1.2
− 0.590115E−02	1.4
− 0.164871E−02	1.6
0.217857E−03	1.8
0.570068E−03	2.0
0.374110E−03	2.2
0.140190E−03	2.4
0.129576E−04	2.6
− 0.248459E−04	2.8
− 0.218420E−04	3.0
− 0.102654E−04	3.2
− 0.231793E−05	3.4
0.791813E−06	3.6
0.116585E−05	3.8
0.679702E−06	4.0

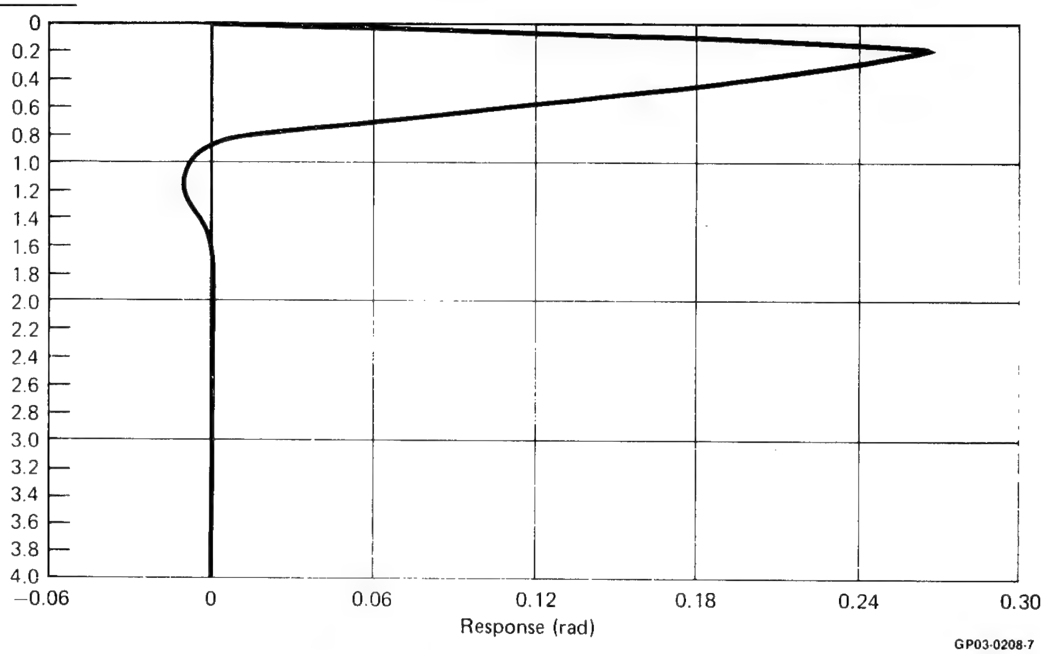


Figure 6. Lateral Dynamics, ϕ/δ_{ST}
N2LAT

(d) Longitudinal Dynamics - These were held constant in the experiment, and were modeled by a 0/2nd transfer function of the form:

$$\frac{\Theta}{\delta_{ST}} = \frac{.591 \text{ rad/sec}^2\text{/cm}}{[.7;2.0]}$$

Time histories for step and impulse functions are presented in Figure 7. Again the impulse histories confirm that the longitudinal dynamics are categorized as attitude systems.

(e) Directional Dynamics - These were held constant in the experiment and were modeled by a 0/1st transfer function of the form:

$$\frac{\dot{\psi}}{\delta_{Pedal}} = \frac{.115 \text{ rad/sec}^2\text{/cm}}{(1.095)}$$

Time history responses for step and impulse functions are shown in Figure 8.

(f) Thrust-to-Throttle Dynamics - These were held constant in the experiment, and were modeled with a second order lag representative of the YAV-8B Pegasus response. The maximum thrust-to-weight ratio was 1.1. Trim was set at approximately 90% throttle.

The block diagram for thrust-to-throttle response is shown in Figure 9.

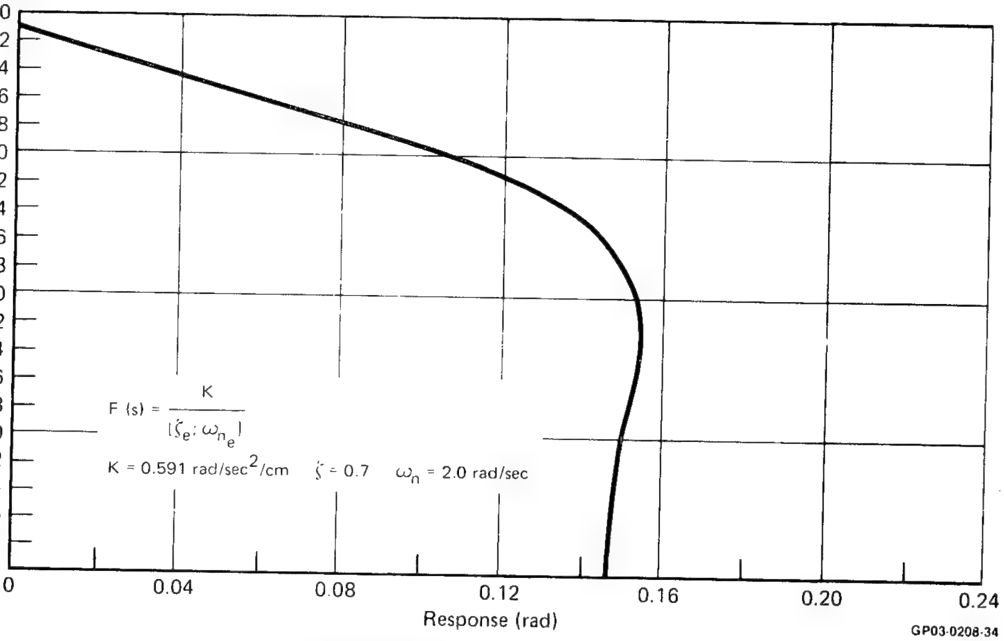
3. EQUATIONS OF MOTION - The equations of motion used in the simulation are presented in Table 1.

Simulator display motions were driven by six degree of freedom calculations.

4. GUSTS AND TURBULENCE - Continuous turbulence was simulated by passing the output of a random noise generator having a relatively uniform low-frequency power spectral distribution through a first order filter with a break frequency (ω_B) of 0.314 rad/sec:

Step Response
1 cm Input

Tabulated Response (rad)	Time (sec)
0.888178E–15	0
0.976479E–02	0.2
0.320243E–01	0.4
0.587298E–01	0.6
0.847464E–01	0.8
0.107224E+00	1.0
0.124963E+00	1.2
0.137850E+00	1.4
0.146409E+00	1.6
0.151459E+00	1.8
0.153896E+00	2.0
0.154545E+00	2.2
0.154094E+00	2.4
0.153069E+00	2.6
0.151841E+00	2.8
0.150645E+00	3.0
0.149612E+00	3.2
0.148796E+00	3.4
0.148204E+00	3.6
0.147811E+00	3.8
0.147579E+00	4.0



Impulse Response
1 cm Input

Tabulated Response (rad)	Time (sec)
0.709689E–15	0
0.881236E–01	0.2
0.127807E+00	0.4
0.135023E+00	0.6
0.122821E+00	0.8
0.101003E+00	1.0
0.763296E–01	1.2
0.530079E–01	1.4
0.332779E–01	1.6
0.179849E–01	1.8
0.707504E–02	2.0
– 0.120921E–04	2.2
– 0.405887E–02	2.4
– 0.587972E–02	2.6
– 0.620898E–02	2.8
– 0.564642E–02	3.0
– 0.464245E–02	3.2
– 0.350773E–02	3.4
– 0.243550E–02	3.6
– 0.152859E–02	3.8
– 0.825752E–03	4.0

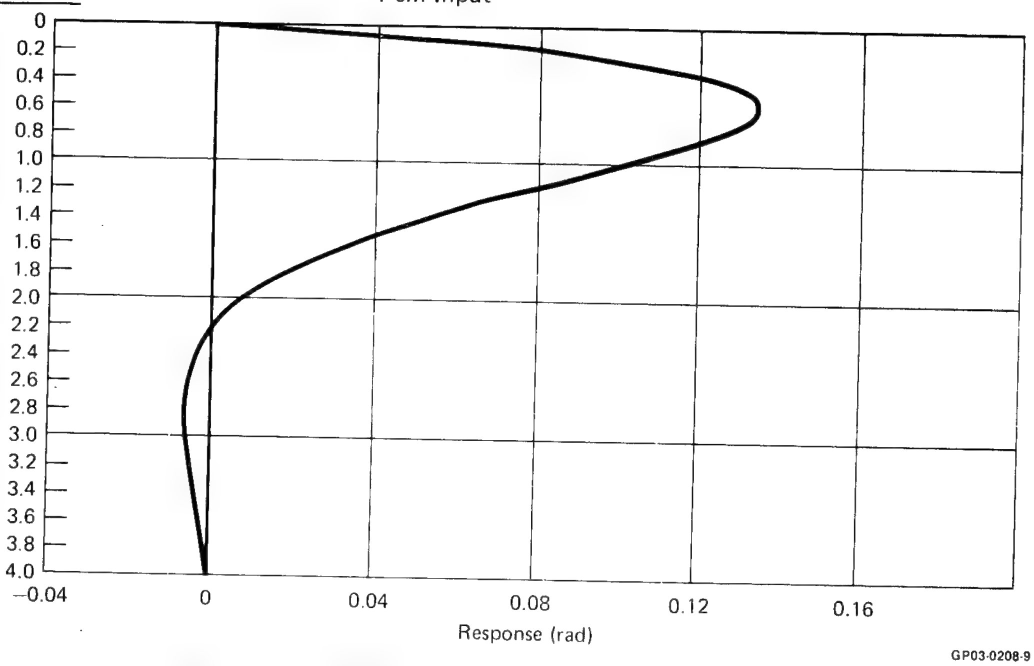
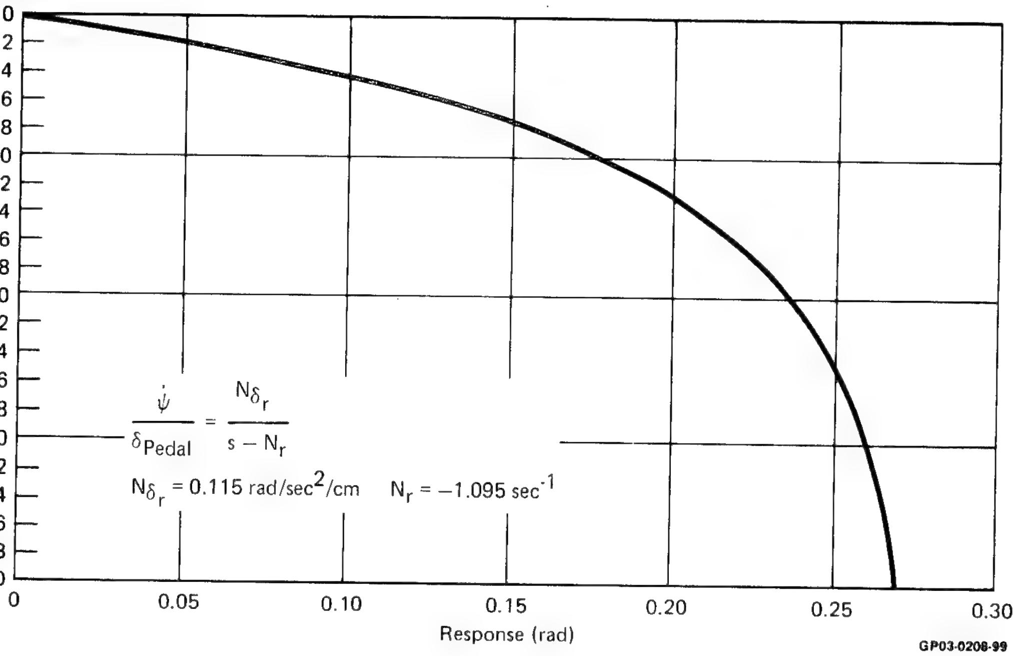


Figure 7. Longitudinal Dynamics, θ/δ_{ST}

Step Response
1 cm Input

Tabulated Response (rad)	Time (sec)
	0
0.524475E−01	0.2
0.945798E−01	0.4
0.128426E+00	0.6
0.155615E+00	0.8
0.177456E+00	1.0
0.195002E+00	1.2
0.209097E+00	1.4
0.220420E+00	1.6
0.229515E+00	1.8
0.236822E+00	2.0
0.242692E+00	2.2
0.247407E+00	2.4
0.251195E+00	2.6
0.254238E+00	2.8
0.256683E+00	3.0
0.258646E+00	3.2
0.260224E+00	3.4
0.261491E+00	3.6
0.262509E+00	3.8
0.263327E+00	4.0



Impulse Response
1 cm Input

Tabulated Response (rad)	Time (sec)
0.292000E+00	0
0.234570E+00	0.2
0.188435E+00	0.4
0.151374E+00	0.6
0.121602E+00	0.8
0.976856E−01	1.0
0.784729E−01	1.2
0.630390E−01	1.4
0.506406E−01	1.6
0.406807E−01	1.8
0.326797E−01	2.0
0.262523E−01	2.2
0.210890E−01	2.4
0.169413E−01	2.6
0.136093E−01	2.8
0.109327E−01	3.0
0.878244E−02	3.2
0.705512E−02	3.4
0.566753E−02	3.6
0.455285E−02	3.8
0.365740E−02	4.0

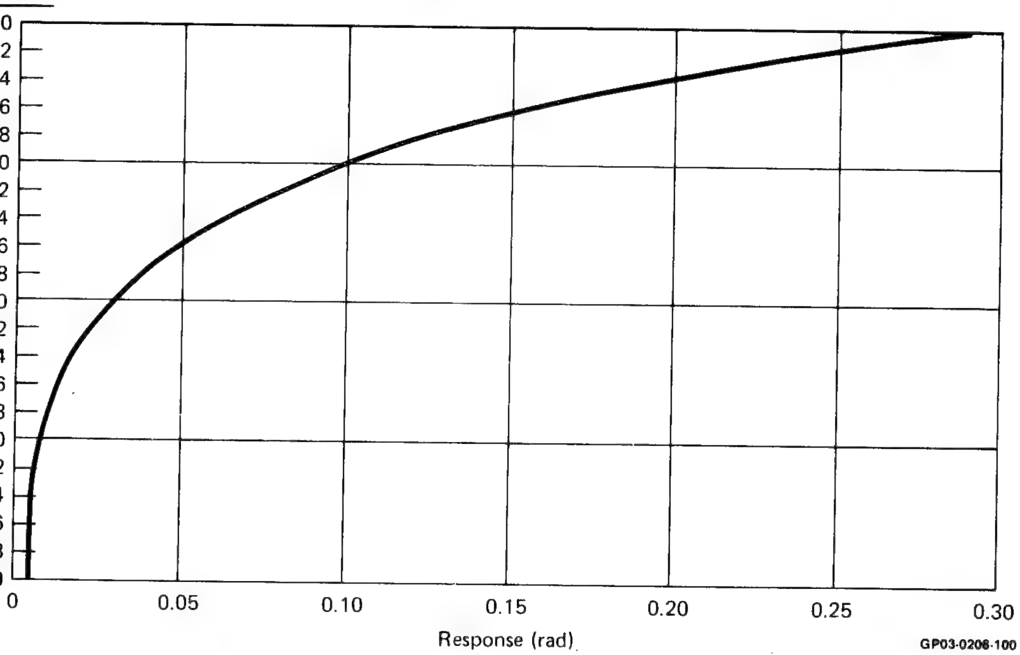
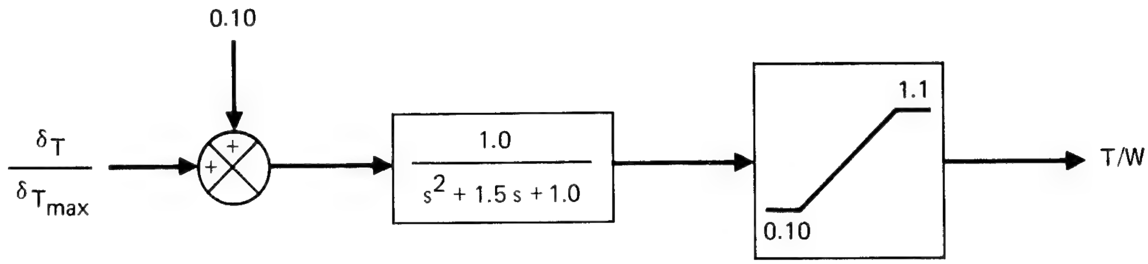


Figure 8. Directional Control, $\dot{\psi}/\delta_{PED}$



$$T/W = 0.10 + \frac{\delta_T}{\delta_{T_{max}}}$$

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Figure 9. Thrust-to-Throttle Dynamics

TABLE 1. EQUATIONS OF MOTION

1. **Transfer functions yield p, q, r (body axis angular rates).**
2. **Body axis velocity components obtained from:**

$\dot{u} = -g \sin\theta + rv - qw + X_u u$ $\qquad X_u = -0.1$

$\dot{v} = g \sin\phi \cos\theta + pw - ru + Y_v v$ $\qquad Y_v = -0.1$

$\dot{w} = -pv + qu - g\,(T/W - \cos\theta \cos\phi) + Z_w w$ $\qquad Z_w = -0.75$

3. **Inertial axis displacement determined from:**

$\dot{X} = u \cos\psi \cos\theta + v[\cos\psi \sin\theta \sin\phi - \sin\psi \cos\phi] + w\,[\cos\psi \sin\theta \cos\phi + \sin\psi \sin\phi]$

$\dot{Y} = u \sin\psi \cos\theta + v\,[\sin\psi \sin\theta \sin\phi + \cos\psi \cos\phi] + w\,[\sin\psi \sin\theta \cos\phi - \cos\psi \sin\phi]$

$\dot{Z} = -u \sin\theta + v \cos\theta \sin\phi + w \cos\theta \cos\phi$

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$$\frac{u_g}{N_g} = \frac{K_{u_g}}{S + 0.314}$$

$$\frac{v_g}{N_g} = \frac{K_{v_g}}{S + 0.314}$$

where K_{u_g} and K_{v_g} were adjusted to yield desired rms values of turbulence. N_g is the output of the random noise generator.

The continuous turbulence intensity level was σ_g = 1.14 kt (1.925 fps). For the lateral handling qualities study, the longitudinal component u_g was 25% of the lateral component v_g. The components were in phase. Turbulence was introduced along the aircraft X and Y body axes through the display. The continuous turbulence did not produce severe problems for the pilot and was rated as a minor nuisance.

In addition to the continuous turbulence, large discrete disturbances along the aircraft Y body axis were input to the display. These "spikes" appeared to the pilot as strong side gusts producing large excursions from the flight path.

The crosswind spike magnitude was established during the check-out phase by progressively increasing rate magnitudes from 0.6096 to 3.048 meters per second squared. A maximum spike rate of 1.524 meters per second squared for 5.0 seconds, followed by a decay at the same rate, gave a realistic but demanding external disturbance. This produced a maximum aircraft translation rate of 14.8 kts (25 fps).

The pilots were asked to maintain a constant heading when encountering the spike, which was input at random times by the engineer. Since the spike was a gross disturbance in the aircraft's position, it forced the pilot to evaluate both flight path control (outer loop) and attitude control (inner loop). Thus its implementation was analogous to the CTOL offset precision landings which have been shown to expose flying qualified problems very reliably.

A strip chart recording of the low frequency turbulence and crosswind spike (wind shear) is shown in Figure 10 for a typical run.

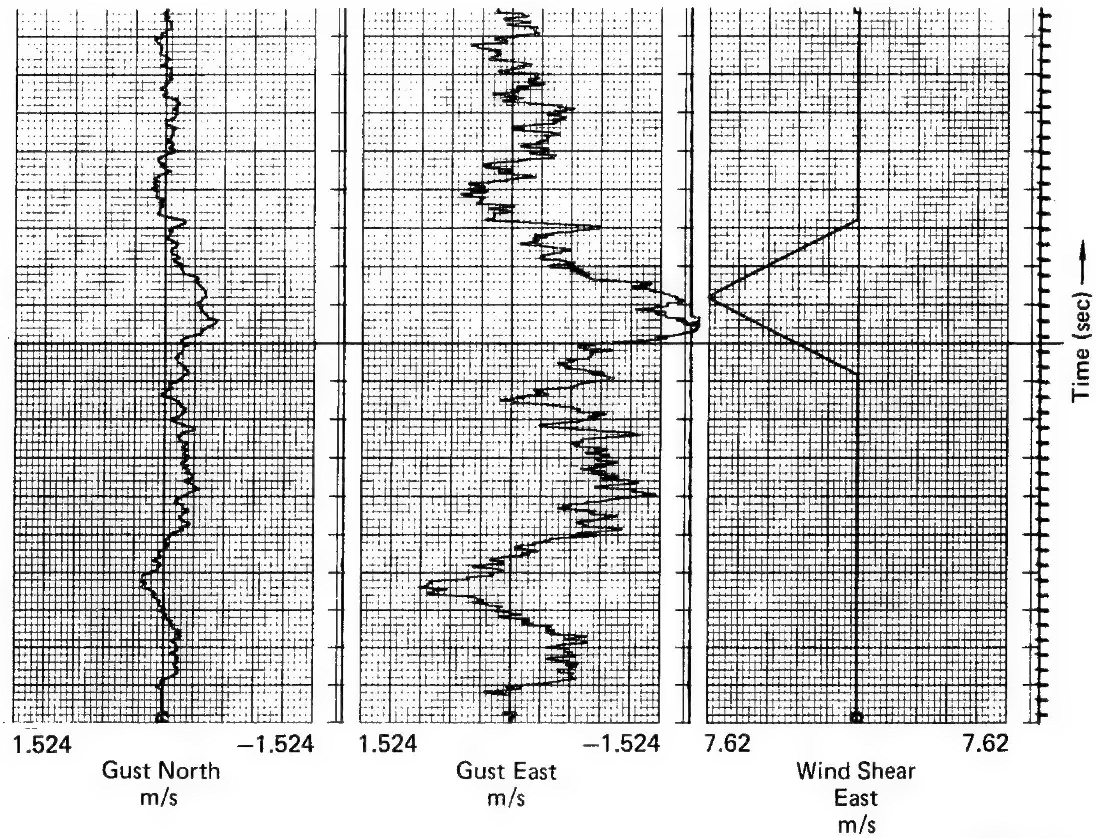

Figure 10. Typical Strip Chart Recordings of Wind Gusts and Crosswind "Spikes"

5. PILOT TASK - The aircraft was initially at an altitude of 18.288m (60 ft) with a 14.8 kts (25 fps) forward speed and was centered on the runway approximately 30.48m (100 ft) laterally and 60.96m (200 ft) longitudinally from the hover point. The task was to translate forward and to the right and stabilize in hover over a point on the right edge of the runway and slightly displaced from the intersection of the runway with the taxi-way. A sketch depicting the task is shown in Figure 11. As a secondary task, the pilots tried to maintain a constant altitude of 18.288m (60 ft). The pilots were also asked to maintain a constant heading down the runway. Normal piloting technique would be to yaw into the wind spike. By maintaining a relatively constant heading instead, it was hoped to expose any piloting problems with the lateral axis.

6. PILOT COMMENT AND RATING SHEET - A pilot comment and rating sheet was used to stimulate the pilots thinking in the areas of interest. The sheet covered areas of general interest, e.g. attitude response, flight path response and wind and turbulence, with more precise topics under the general headings. A sample comment sheet is shown in Figure 12.

The pilots were also given a Cooper-Harper rating scale card to be used in rating each configuration. A sample rating card is shown in Figure 13.

7. Added High Order Dynamics - As discussed in the Introduction, high order terms were cascaded with (i.e. added to) the low order nominal dynamics at high and low frequencies, to gain information on the four basic questions of equivalence. Appendix A contains transfer function coefficient and root data, with frequency and time responses, for all configurations. The response of each configuration is compared with the corresponding nominal dynamics.

8. Low Frequency Dynamics - Two types of low frequency dynamics were added separately to the nominal dynamics.

The first was a second order element of the form

$$\frac{\omega_L^{\,2} s^2}{[.05;\omega_L]} \quad \text{with } \omega_L = .1,\ .3,\ .5,\ .7 \text{ rad/sec}$$

It combines two low frequency effects which can be seen in practical flight control systems. The first is the localized amplitude resonance due to low damping, and the second is a 40 dB/decade low frequency gain roll-off. This roll-off is an exaggeration of the low frequency behavior of the 'rooftop' systems in Figure 28 of Reference 1. The advantage of the roll-off in this study is the smooth progressive increase in mismatch it introduces when ω_L is increased.

These data are presented in Appendix B as pilot comments and ratings only.

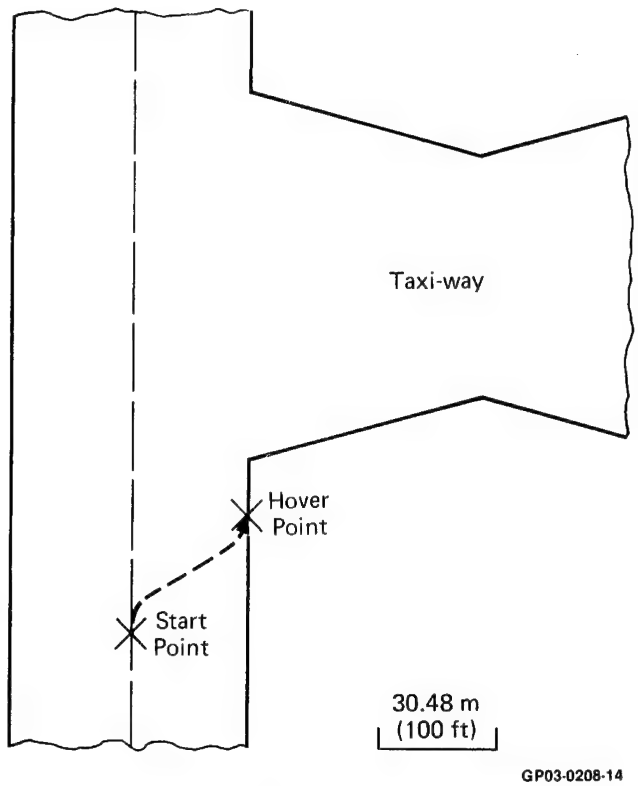

Figure 11. Diagram of Pilot Task

	Translation	Hover
	Overall Rating:	Overall Rating:
Feel • Forces • Displacement • Sensitivity		
Attitude Response • Initial • Predictability • Special Inputs • PIO Tendency		
Flight Path Response • Initial • Predictability • Special Inputs • Flight Path and Attitude Trade-offs		
Height Response • Special Problems		
Wind and Turbulence • Effect on Attitude • Effect on Altitude, Flight Path and/or Height Response		
Summary Comments		

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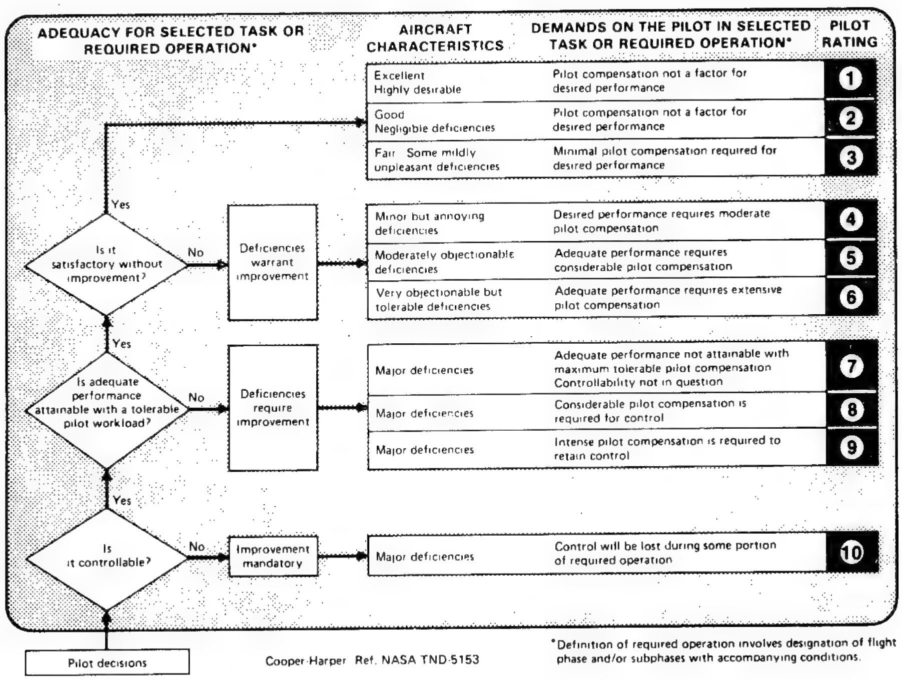
Figure 12. Pilot Comment and Rating Sheet



DEFINITIONS FROM TN-D-5153

COMPENSATION

The measure of additional pilot effort and attention required to maintain a given level of performance in the face of deficient vehicle characteristics.

HANDLING QUALITIES

Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role

MISSION

The composite pilot-vehicle functions that must be performed to fulfill operational requirements. May be specified for a role, complete flight, flight phase, or flight subphase

PERFORMANCE

The precision of control with respect to aircraft movement that a pilot is able to achieve in performing a task. (Pilot-vehicle performance is a measure of handling performance. Pilot performance is a measure of the manner or efficiency with which a pilot moves the principal controls in performing a task.)

ROLE

The function or purpose that defines the primary use of an aircraft.

TASK

The actual work assigned a pilot to be performed in completion of or as representative of a designated flight segment

WORKLOAD

The integrated physical and mental effort required to perform a specified piloting task

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Figure 13. Cooper-Harper Pilot Rating Scale

The second type of low frequency dynamics was a dipole of the form

$$\frac{[.2;\omega_{DP}]}{[.7;\omega_{DP}]} \quad \text{with } \omega_{DP} = .1,\ .3,\ .5,\ .7 \text{ rad/sec}$$

This dutch roll-like, dipole mode was established after examining responses of the YAV-8B and Type A V/STOL. It adds a localized notch to the frequency response. By changing the frequency of the notch, ω_{DP}, information on the pilots' sensitivity to low frequency mismatches was gained.

9. High Frequency Dynamics - To generate high frequency mismatches, three types of high frequency dynamics (first order lag, second order lag, transport lag) were added separately to the two nominal systems. The frequency of the first and second order lags was decreased and the delay increased progressively. These dynamics are typical of the high order effects of prefilters, actuation, etc., which can be seen in many augmented systems. The form of each added term is indicated below:

a. First Order Lags

$$\frac{1}{(\lambda)} \quad \text{with } \lambda = 1.,\ 2.,\ 3.,\ 4.,\ 5.,\ 6.,\ 7. \text{ rad/sec}$$

b. Second Order Lags

$$\frac{\omega_L^2}{[.3;\omega_L]} \quad \text{with } \omega_L = 4.,\ 5.,\ 6.,\ 7.,\ 8.,\ 9.,\ 10.,\ 11. \text{ rad/sec}$$

This damping ratio of .3 is lower than those usually due to high frequency control components, which have a damping ratio around .7. By introducing a mode with an oscillation, it was hoped to introduce a somewhat different piloting effect from the apparent delay which a well-damped second order mode would introduce.

c. Transport Lags - Pure time delay, $e^{-\tau s}$, was added to the nominal systems to investigate the effects of time delay on pilot performance. For N2LAT, the time delay was adjusted to produce the same amount of phase lag at the nominal frequency as was produced for N1LAT at its nominal frequency. For example, time delay of .2 sec will produce 23.0 degrees of phase lag at N1LAT's natural frequency of 2.0 rad/sec. Equivalently, a time delay of .08 sec will also produce 23.0 degrees of phase lag at N2LAT's natural frequency of 5.0 rad/sec. Time delay values of .2, .3 and .4 sec were also investigated for N2LAT. The time delays added to each nominal system, together with the added phase lag at the natural frequency, are tabulated below.

Time delay for N1LAT, Sec	.1	.2	.3	.4			
Time delay N2LAT, Sec	.05*	.08	.12	.16	.2	.3	.4
Phase Lag At Natural Frequency, Degrees	11 (14*)	23	34	46	57	86	115

*A value of .05 seconds was used for computational simplicity instead of the true equivalent of .04 seconds.

III RESULTS OF THE SIMULATION

1. EFFECTS OF THE DISPLAY - The VITAL IV display was considered by the pilots to be very realistic. Of the types of display available, the twilight scene appeared the most realistic for simulating conditions close to the ground. In the bright daylight scene, additional surface detail and texture seemed to be needed. The night scene was highly realistic, with lights on surrounding runways, taxiways, structures and distant city lights, but the ground plane was not visible. In this respect, the night scene was an excellent simulation of operation close to the ground without a landing light. However, the twilight scene, with both ground plane simulation and the ground lights, offered the best combination of cues.

The refresh rate in the display was 20 Hz. The pilots commented that this produced slight but noticeable stair-stepping for N2LAT, which was deliberately chosen to be rapid. This effect did not appear to degrade the flying qualities. One pilot, who was experienced in the X-22 in-flight simulator, felt an additional unnatural effect, possibly due to vestibular conditioning, which he thought was not solely due to the high bandwidth of N2LAT.

Altitude cues were noticeably weaker in the outside world display than in actual flight. The heads-up display (HUD) replaced this cue to a large extent, however, additional information (for example altitude rate on the HUD) would be helpful for simulation of actual touchdown.

The pilots attempted to extrapolate the simulation to actual touchdown. In their opinion, some of the systems rated Level 1 and Level 2 for hovering and low speed conditions would be less satisfactory in actual touchdown. The following results should be viewed with this in mind.

2. PILOT COMMENTS AND RATINGS - Table 2 summarizes all the rating data for all configurations. Appendix B contains the pilot comments in full. All the pilot rating plots which follow show the average rating for each pilot.

3. CALCULATION OF MISMATCHES - Wherever mismatches are mentioned, a MCAIR frequency response computer program was used. This program calculates the mismatch between two systems expressed as the sum of squared differences in gain and phase, using

$$\frac{20}{n} \sum (\text{Gain}_{HOS} - \text{Gain}_{LOS})^2 + .02\ (\text{Phase}_{HOS} - \text{Phase}_{LOS})^2$$

where n is the number of frequencies chosen within the frequency range of match.

TABLE 2. LIST OF CONFIGURATIONS AND PILOT RATINGS

	Nominal			Nuisance Mode					Pilot Rating			
Config	Gain	ζ	ω_n	τ (Equiv ϕ)	λ	ζ_N	ζ_D	ω_L or DP	A	B	C	D
N1LAT	0.6	0.7	2.0	–	–	–	–	–		4.5,4,3.5		4,7,4
	0.45			–	–	–	–	–	4,4,4,4,3,3,3,2,3, 3,3,3,4,3,3,3,2,2, 5,4	3.5,3,4,3.5 3.5	7,5	
	0.3			–	–	–	–	–		3.5,5		3
N2LAT	0.3		5.0	–	–	–	–	–	4,4,4,4,5,3,3,3,3, 3,3,5,4,4,5,4,3,	6.5,5,3.5,5 5,5	5,4	5
HF111	0.45		2.0	–	1.0	–	–	–	7,7,9,7			
HF112				–	2.0	–	–	–	5,8,6,6			
HF113				–	3.0	–	–	–	6,4,3,5,6			
HF114	0.6			–	4.0	–	–	–		4		
	0.45			–		–	–	–	5,6			
HF115	0.3			–	5.0	–	–	–		3.5		
	0.45			–		–	–	–	5,4		6	
HF116	0.6			–	6.0	–	–	–				5
	0.45			–		–	–	–	5	4.5		
HF117	0.3			–	7.0	–	–	–		4.5		
HF124	0.6			–	–	–	0.3	4.0		6		
	0.45			–	–	–			6	7.5		
HF125	0.6			–	–	–		5.0				7.5
	0.45			–	–	–			5	6		
	0.3			–	–	–			6			
HF126	0.45			–	–	–		6.0	6,5	4,4		
HF127				–	–	–		7.0	7,6			
	0.3			–	–	–				5.5		
HF128	0.45			–	–	–		8.0	4,5			
HF129				–	–	–		9.0	3,4,4,4			
HF120				–	–	–		10.0	5,5,3,4			
HF121				–	–	–		11.0	6,4,5			

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TABLE 2. (Continued) LIST OF CONFIGURATIONS AND PILOT RATINGS

	Nominal			Nuisance Mode					Pilot Rating			
Config	Gain	ζ	ω_n	τ (Equiv ϕ)	λ	ζ_N	ζ_D	ω_L or DP	A	B	C	D
HF1T1	0.6	0.7	2.0	0.1 (11.46°)	–	–	–	–				6
	0.45				–	–	–	–	4,2			
	0.3				–	–	–	–		5		
HF1T2	0.45			0.2 (22.92°)	–	–	–	–	7,7	6.5	6	
HF1T3	0.6			0.3 (34.38°)	–	–	–	–		4		
	0.45				–	–	–	–	7	5.5		
HF1T4	0.3			0.4 (45.84°)	–	–	–	–		7		
	0.45				–	–	–	–	7			
LF121	0.45			–	–	0.2	0.7	0.1	3		4	
LF123				–	–			0.3	2,3			
LF125				–	–			0.5	3,4			
LF127				–	–			0.7	4,7		8	
LF121*	0.6			–	–	–	0.05	0.1				3
LF123*				–	–	–		0.3				7
LF125*				–	–	–		0.5				10
LF127*				–	–	–		0.7				10
HF211	0.3		5.0	–	1.0	–	–	–	6,6,5,6,6			
HF212				–	2.0	–	–	–	2,3,3,5			
HF213				–	3.0	–	–	–	3,4,3,3			
HF214				–	4.0	–	–	–	3	3.5		
HF215				–	5.0	–	–	–	3	3,4.5	5	
HF216				–	6.0	–	–	–	3	4		
HF217				–	7.0	–	–	–	3		5	
HF224				–	–	–	0.3	4.0	7	5		
HF225				–	–	–		5.0		7,8	7	
HF226				–	–	–		6.0	6,6	5.5		
HF227				–	–	–		7.0	6	5,6	6	
HF228				–	–	–		8.0	8,4,4,6			
HF229				–	–	–		9.0	5,4,3			
HF220				–	–	–		10.0	4,8,3			

*Exaggerated rooftop systems

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TABLE 2. (Concluded) LIST OF CONFIGURATIONS AND PILOT RATINGS

	Nominal			Nuisance Mode					Pilot Rating			
Config	Gain	ζ	ω_n	τ (Equiv ϕ)	λ	ζ_N	ζ_D	ω_L or DP	A	B	C	D
HF221	0.3	0.7	5.0	–	–	–	0.3	11.0	7,4,2,4			
HF2T1				0.05 (14.33°)	–	–	–	–	3	3,4.5	5	
HF2T2				0.08 (22.92°)	–	–	–	–	2,3	5		
HF2T3				0.12 (34.38°)	–	–	–	–	3	5		
HF2T4				0.16 (45.84°)	–	–	–	–	5,5,5,5	6.5		
HF2T5				0.2	–	–	–	–	6,6			
HF2T6				0.3	–	–	–	–	8,5,5			
HF2T7				0.4	–	–	–	–	8,9			
LF221				–	–	0.2	0.7	0.1	3			
LF223				–	–			0.3	4		8	
LF225				–	–			0.5	6			
LF227				–	–			0.7	6			
LF221*				–	–	–	0.05	0.1				5
LF223*				–	–	–		0.3				
LF225*				–	–	–		0.5				
LF227*				–	–	–		0.7				
G110	1.0		2.0	0 (0°)	–	–	–	–	3, 2, 3, 2			
G111				0.1 (11.46°)	–	–	–	–	6,6			
G112				0.2 (22.92°)	–	–	–	–	8.5, 8, 7	6		
G113				0.3 (34.38°)	–	–	–	–	7	10		
G120	0.2			0 (0°)	–	–	–	–	7,7			
G121				0.1 (11.46°)	–	–	–	–	7,7			
G122				0.2 (22.92°)	–	–	–	–	7,7,4	7		
G180	0.8			0 (0°)	–	–	–	–	2,4			
G186				0.06 (6.88°)	–	–	–	–	4,4			
G188				0.08 (9.168°)	–	–	–	–	2,2			
G181				0.1 (11.46°)	–	–	–	–	6,5			

*Exaggerated rooftop systems

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4. LOW FREQUENCY DYNAMICS - The 'rooftop' system caused control difficulties for natural frequencies above 0.1 rad/sec. With an attitude system, and the need for steady state inputs, the reduction in low frequency gain due to the 40 dB/decade roll off appeared to be the culprit. A typical pilot comment was that the control system removed the pilots' input, and eventually the aircraft could be translating to the left, with the control held over to the right stop. These difficulties probably would not have occurred with a translation rate command system, since a steady attitude would not be required for a steady translation rate. This is confirmed by the good ratings obtained with rooftop systems and translation rate control systems in Reference 9.

For the low frequency dipole, the variation of pilot rating with increasing ω_{DP} is shown in Figures 14 and 15. This establishes the allowable low frequency mismatch. It also defines the low frequency threshold for this task, for these nominal dynamics, and for this dipole mode, as follows.

The mismatch between the high order system (nominal plus dipole) and the low order system (nominal alone) was determined for each simulated value of ω_{DP} using a MCAIR frequency response program in a frequency range of 0.1 to 10.0 rad/sec. Mismatch was then compared with the high order system average pilot rating. Figure 16 presents average pilot rating versus mismatch for increasing ω_{DP}. A large mismatch increase for ω_{DP} values between 0.1 to 0.3 rad/sec did not affect the pilot rating. Between 0.3 and 0.5 rad/sec a small change in mismatch occurred but the pilot rating began to be affected. Mismatch was constant for ω_{DP} values above 0.5 rad/sec because all the high order effect of the dipole was contained within the match range. Pilot rating had degraded significantly when ω_{DP} reached 0.7 rad/sec for N1LAT and 0.5 rad/sec for N2LAT. Mismatch values greater than 413 resulted in pilot rating degradation as indicated in Figure 16.

There are two ways of stating this result:

(1) An added dipole of the form $\frac{[.2;\omega_{DP}]}{[.7;\omega_{DP}]}$ will not significantly degrade nominal V/STOL attitude dynamics for $\omega_{DP} < .5$ rad/sec.

(2) A nominal attitude equivalent system with a low frequency, dipole-like mismatch of less than about 400, will adequately model the attitude dynamics for flying qualities analysis of the V/STOL system.

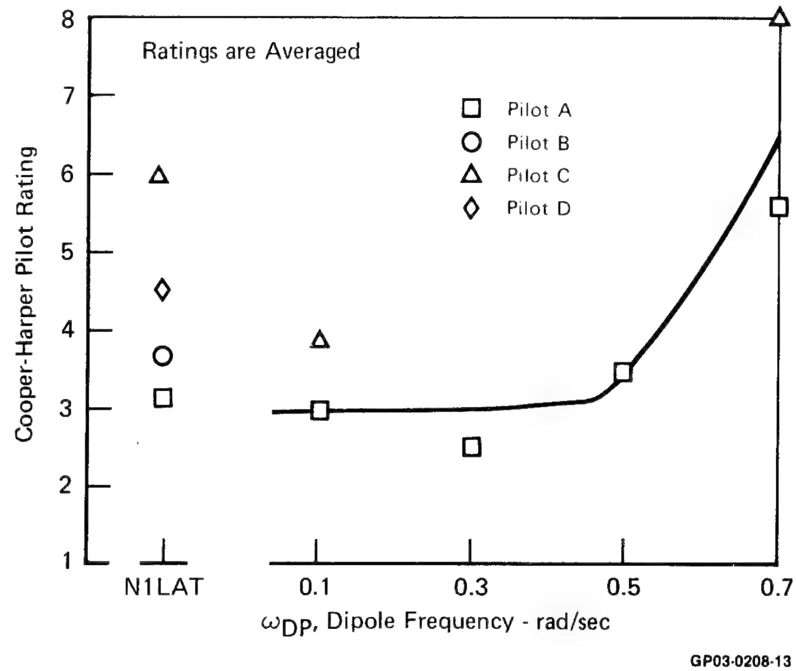

Figure 14. Effect of Dipole Frequency on Pilot Rating
N1LAT

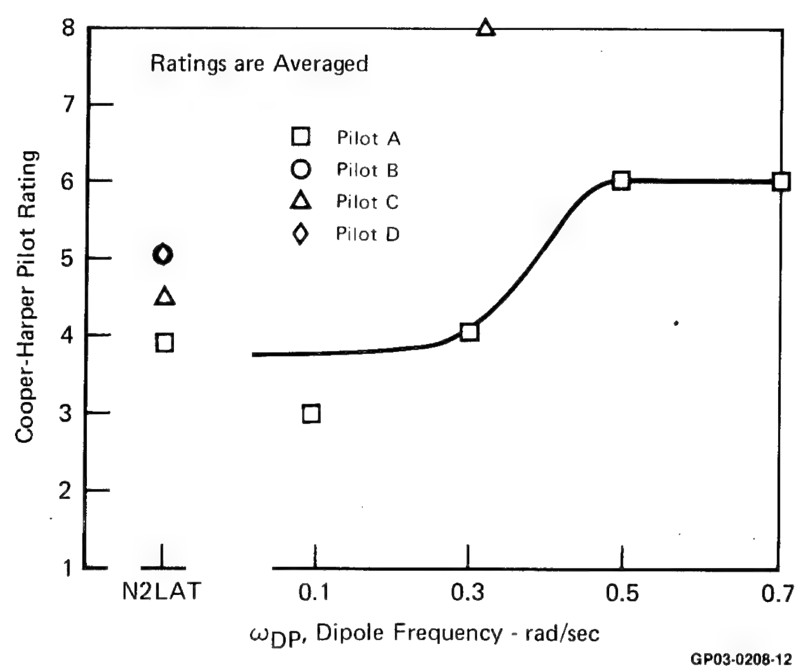

Figure 15. Effect of Dipole Frequency on Pilot Rating
N2LAT

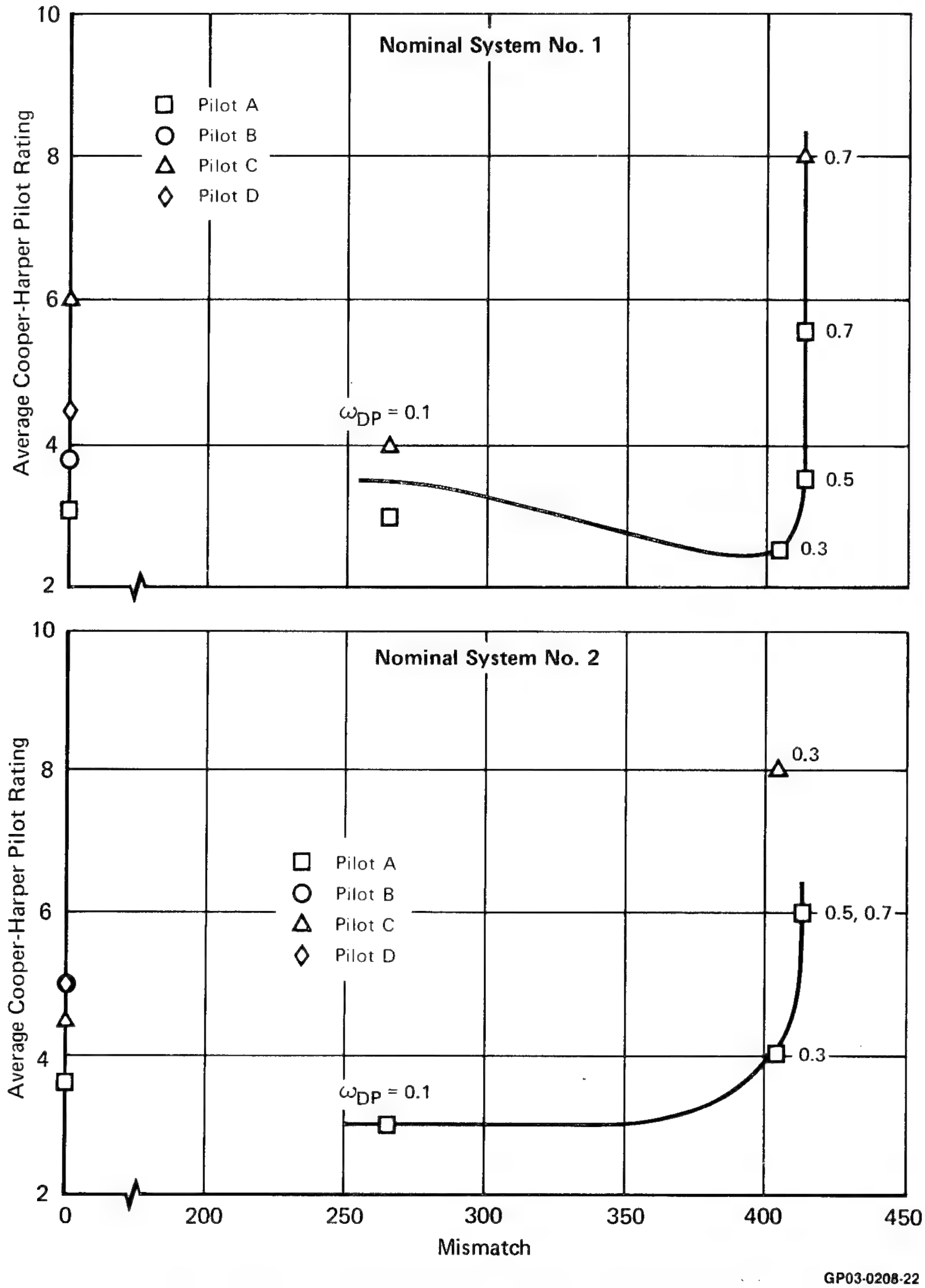

Figure 16. Comparison of Average Pilot Rating and Mismatch for a Dipole Mode Added to N1LAT and N2LAT

Match Frequency Range: 0.1 — 10 Rad/Sec

Ratings are Averaged

This result is reasonably consistent with the earlier MCAIR study of Reference 12. In that study, a lower match frequency of 0.4 rad/sec was used to eliminate a low frequency mode which, though an apparent contaminant to the basic rate response, did not affect the pilot ratings. It was a low frequency instability rather than a dipole. Expanding the match range to 0.1 rad/sec to 10.0 rad/sec and using a first order lag to match the Reference 12 pitch rate response produces a mismatch less than 400.

5. HIGH FREQUENCY DYNAMICS

a. First Order Lags - The effect on average rating of adding a first order lag to the nominal systems is shown in Figures 17 and 18. Adding lag to N1LAT (.708/[.7; 2.0]) degraded the pilot rating at all break frequencies investigated. The rating degraded sharply for break frequencies below 3 rad/sec and reached the Level 2-3 boundary for a break frequency of 2 rad/sec. The rating was 7.5, Level 3, when the break frequency was 1 rad/sec. Adding lag to N2LAT (2.95/[.7; 5.0]) at first improved the pilot rating, with an eventual degradation for large (low frequency) lags. This improved pilot rating is possibly because the lag acts as a prefilter and smoothes out the relatively abrupt N2LAT responses. However, CTOL experience suggests caution in evaluating the rating improvement due to the first order lag prefilter. A more demanding task, in particular an actual touchdown, might show severe piloting problems even for the higher break frequencies. Therefore, the degradation in rating of N1LAT for a break frequency of 7 rad/sec is taken as a minimum threshold for this type of added high frequency effect.

The mismatch between the high order system (nominal plus first order lag) and the low order system (nominal alone) was computed for each simulated value of λ using a MCAIR frequency response program in two frequency ranges of 0.1 to 10 rad/sec and 0.5 to 10.0 rad/sec. Mismatch was then compared with the average pilot rating. Figures 19 and 20 present average pilot rating versus mismatch for increasing λ for the nominal systems. Mismatch increased steadily with decreasing lag frequency. Using a threshold frequency of 7 rad/sec, the corresponding mismatches were:

Frequency Range	Maximum Allowable Mismatch	
0.1 to 10 rad/sec	230.	(data not shown)
0.5 to 10 rad/sec	330.	

Figure 20 presents the comparison of rating and mismatch for a first order lag added to N2LAT. Since the rating improvement with increasing mismatch may be due to the prefilter effect, the previous Figure, showing N1LAT data, was used to establish the threshold. Since the selected threshold frequency was at the limit of the available data, the maximum allowable mismatch may very well be lower than that listed above.

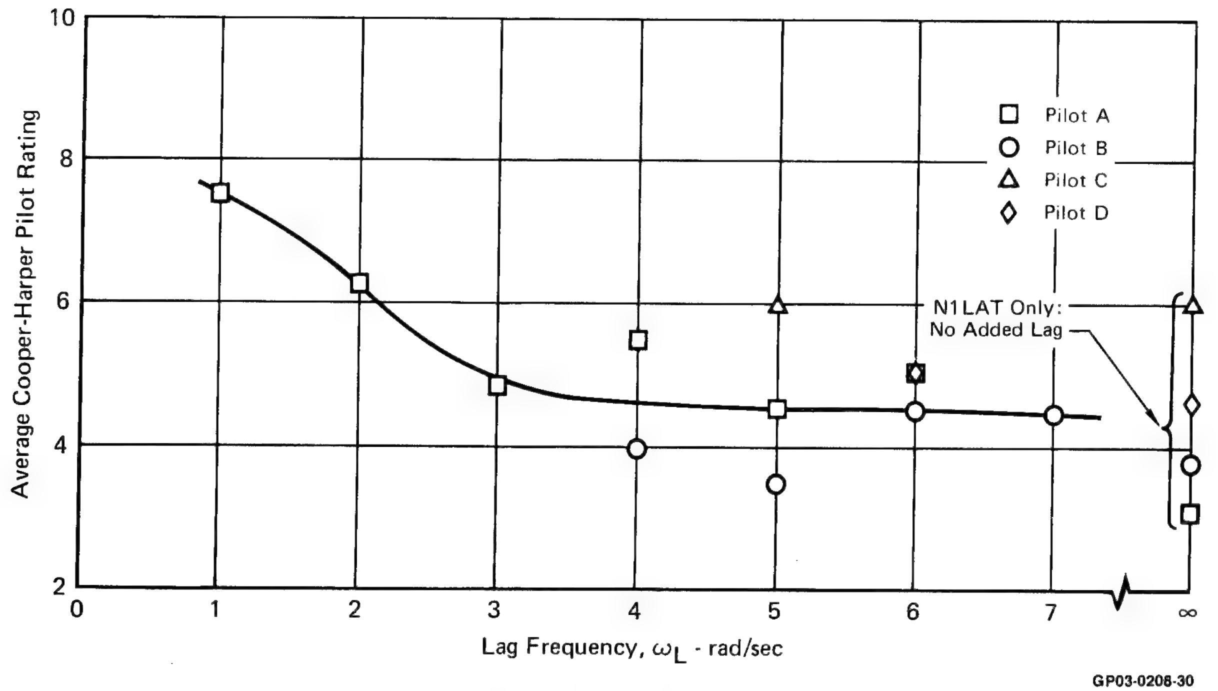

Figure 17. Effect on Pilot Rating of Adding a 1st Order Lag to N1LAT

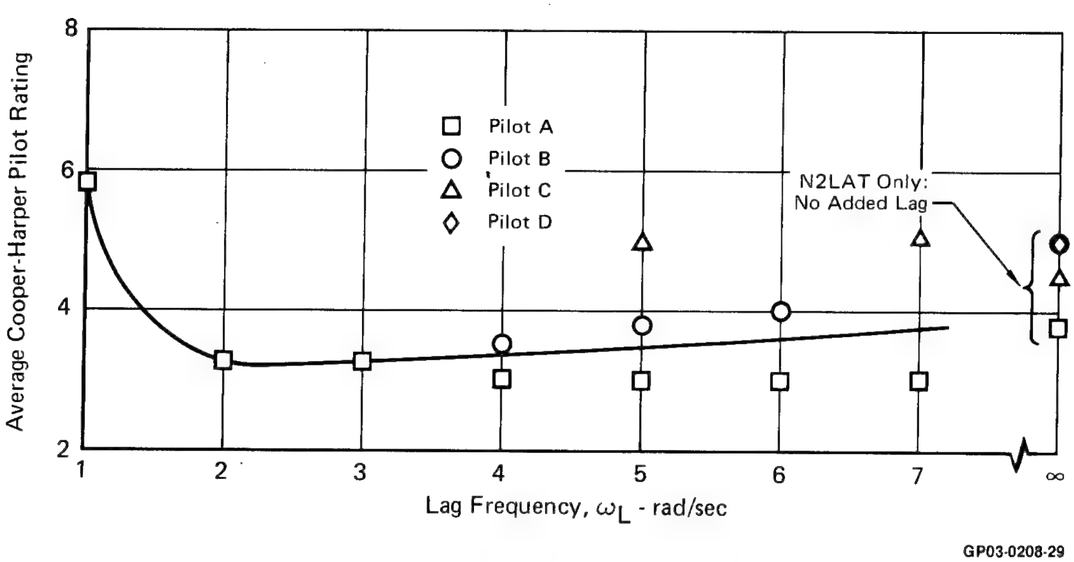

Figure 18. Effect on Pilot Rating of Adding a 1st Order Lag to N2LAT

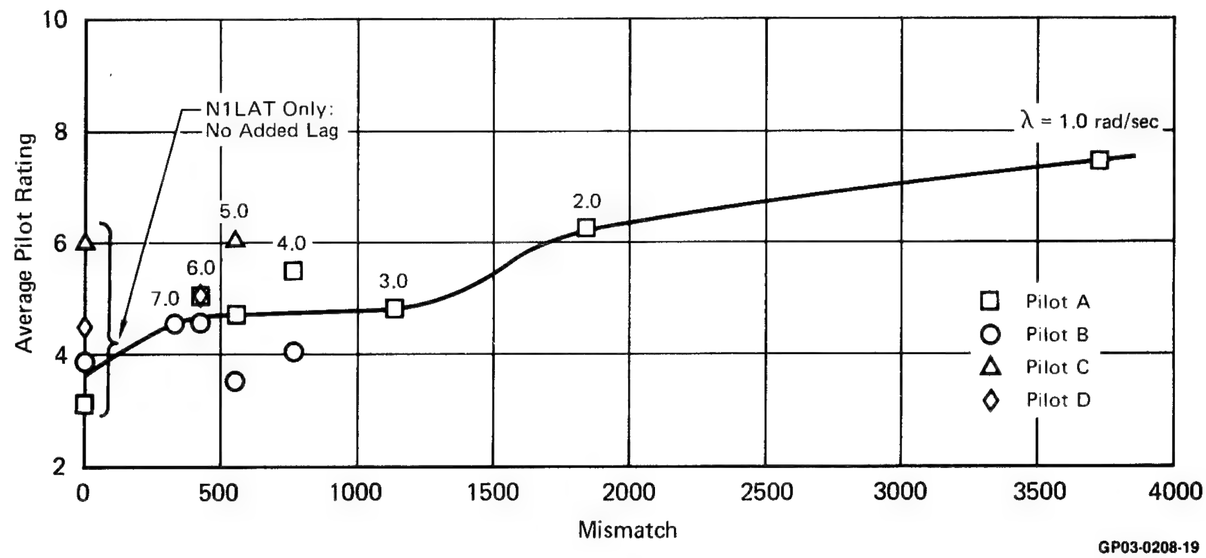

Figure 19. Comparison of Average Pilot Rating and Mismatch for a First Order Lag Added to N1LAT
Match Frequency Range: 0.5 - 10 Rad/Sec

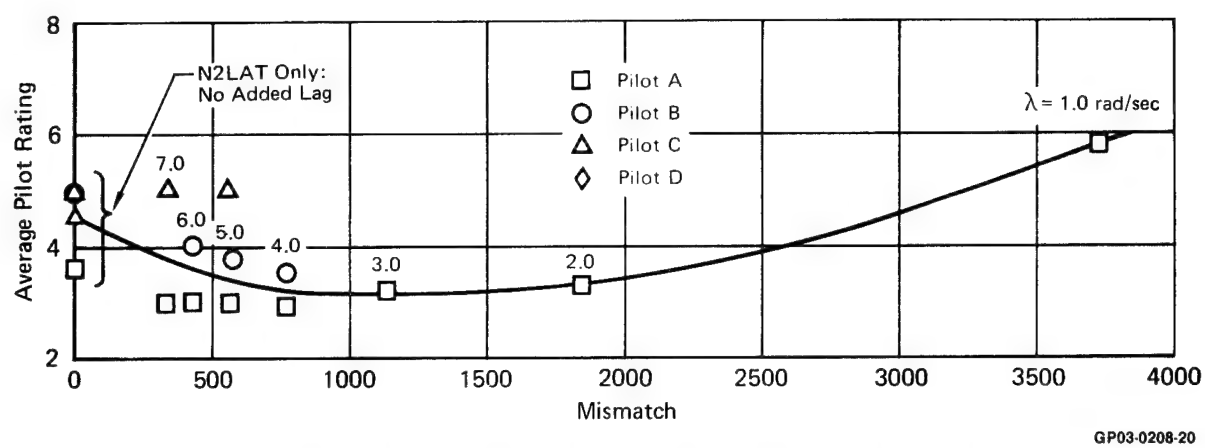

Figure 20. Comparison of Average Pilot Rating and Mismatch for a First Order Lag Added to N2LAT
Match Frequency Range: 0.5 - 10 Rad/Sec

b. Second Order Lags - Figures 21 and 22 present the effects of a second order lag added to the nominal systems. As the lag frequency was decreased, the pilot rating degraded. The N1LAT data indicate a slight degradation in rating even for the small (high frequency) lags, with N2LAT showing an initial slight improvement. However, a conservative threshold would be a limit on second order lags below 10 rad/sec. Again, the threshold here is defined as being where the pilot rating of the nominal plus second order lag is equivalent to the pilot rating of the nominal alone.

Mismatch was computed using the same method for the simulated values of ω_L as was used for first order lags. Figures 23 and 24 present pilot rating versus mismatch for the simulated ω_L for both nominal systems. As with the first order lags, mismatch increased steadily with decreasing ω_L and pilot rating degraded as mismatch increased. Using a threshold frequency of 10 rad/sec, the corresponding mismatches were:

Frequency Range	Maximum Allowable Mismatch
0.1 to 10 rad/sec	260. (data not shown)
0.5 to 10 rad/sec	360.

c. Transport Lags - The effect of pure time delay on pilot opinion rating is presented for both nominal systems in Figure 25. Pilot rating degraded for $\tau > .10$ sec. The results follow a trend similar to that seen in CTOL landing data (Reference 8).

The time delay values do not include the computational time (.008 sec), the sample rate (20 Hertz) nor the equivalent delay due to the stick (.009 sec). The time delay values shown are only the amount of pure time delay added to the system. This is equivalent to ignoring an additional equivalent time delay of .008 + 1/2(.05) + .009 = .042 seconds.

Mismatch was computed in the same manner as for first and second order lags. Time delay versus mismatch is shown in Figure 26. Average pilot ratings are listed next to each data point. The mismatch contribution due to a time delay is 57.3 $\Sigma(\omega t)^2$, with the summation taken over the chosen frequencies. The mismatch is in phase alone. Figures 25 and 26 indicate a mismatch value above 200 (τ = .10) is significant.

6. PILOTING EFFECTS OF PURE TIME DELAY VS PHASE LAG - MCAIR research on augmented CTOL dynamics has investigated whether phase lag at the configuration natural frequency is a more appropriate correlating parameter than delay, (Reference 4). MIL-F-8785B requirements on surface phase lag at the configuration natural frequency imply that a given delay will be more troublesome at higher basic configuration natural frequencies. The requirements are based on the conventional airplane data of DiFranco (Reference 13). However, later results indicate that a given delay will produce a given rating degradation regardless of configuration natural frequency (References 4 and 14). The observed sensitivity of rating to delay is not consistent with the previously held observation that piloted crossover frequency is in the 1. -3. radians/second range, i.e., roughly in the usual range of configuration natural frequencies. At these relatively low frequencies, significant delays introduce apparently insignificant phase lags.

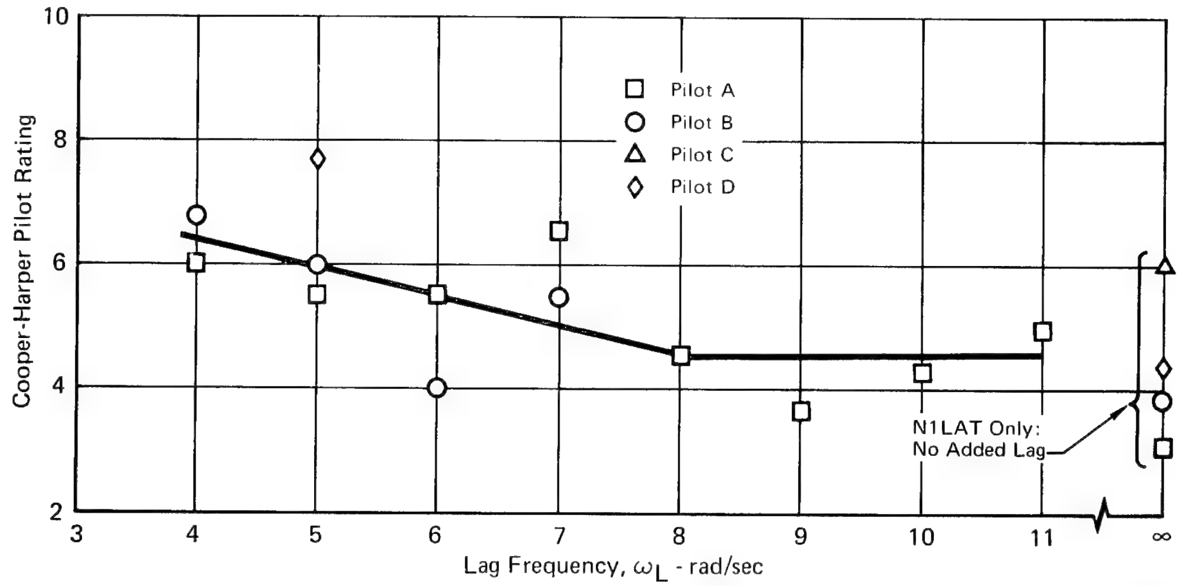

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Figure 21. Effect on Pilot Rating of Adding a 2nd Order Lag to N1LAT

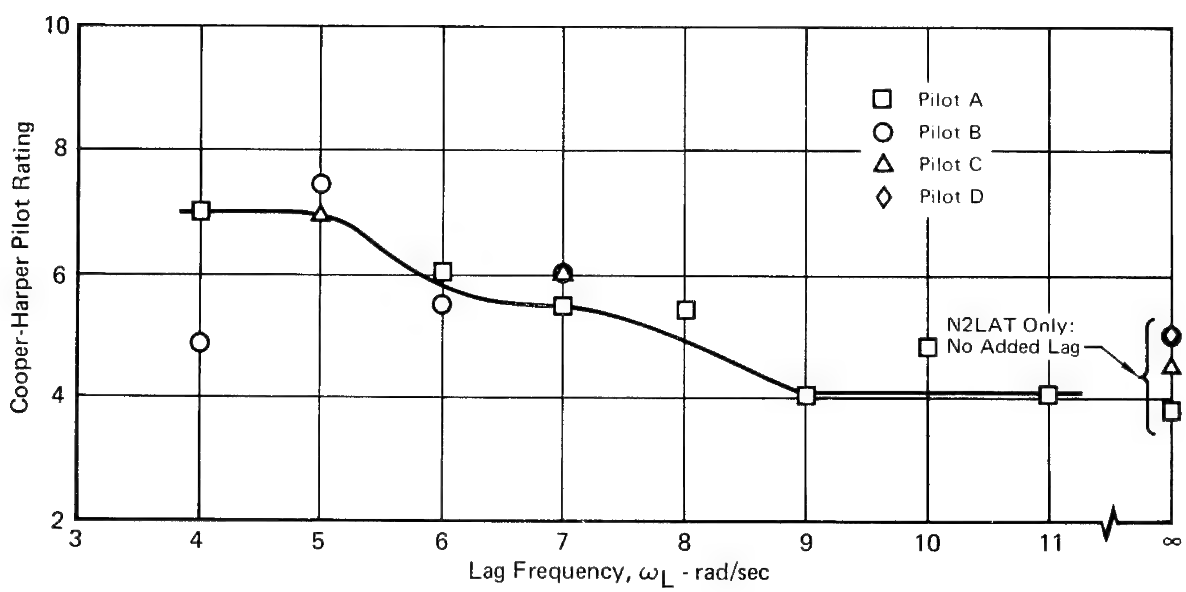

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Figure 22. Effect on Pilot Rating of Adding a 2nd Order Lag to N2LAT

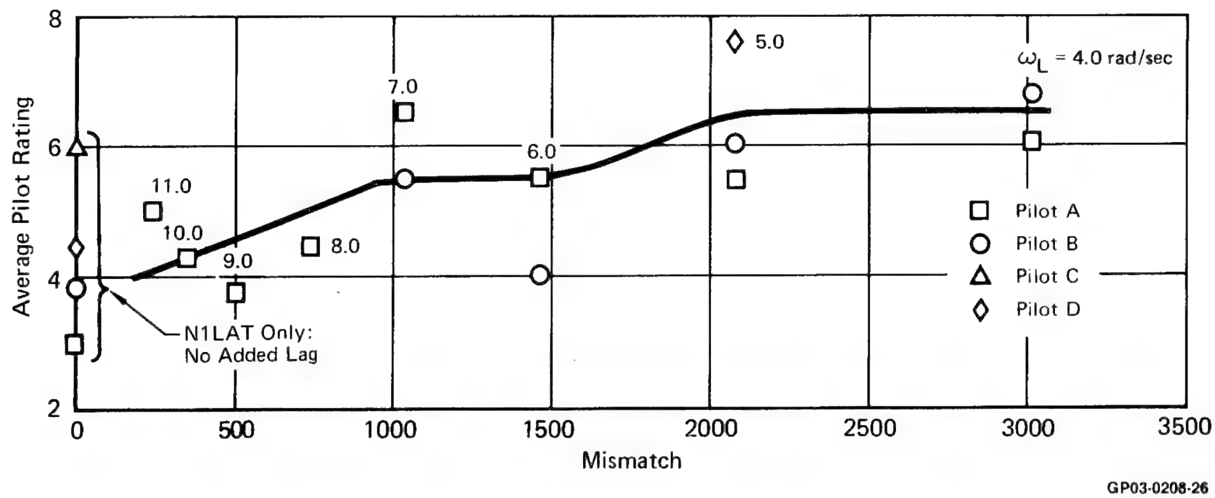

Figure 23. Comparison of Average Pilot Rating and Mismatch for a 2nd Order Lag Added to N1LAT

Match Frequency Range: 0.5 - 10 Rad/Sec

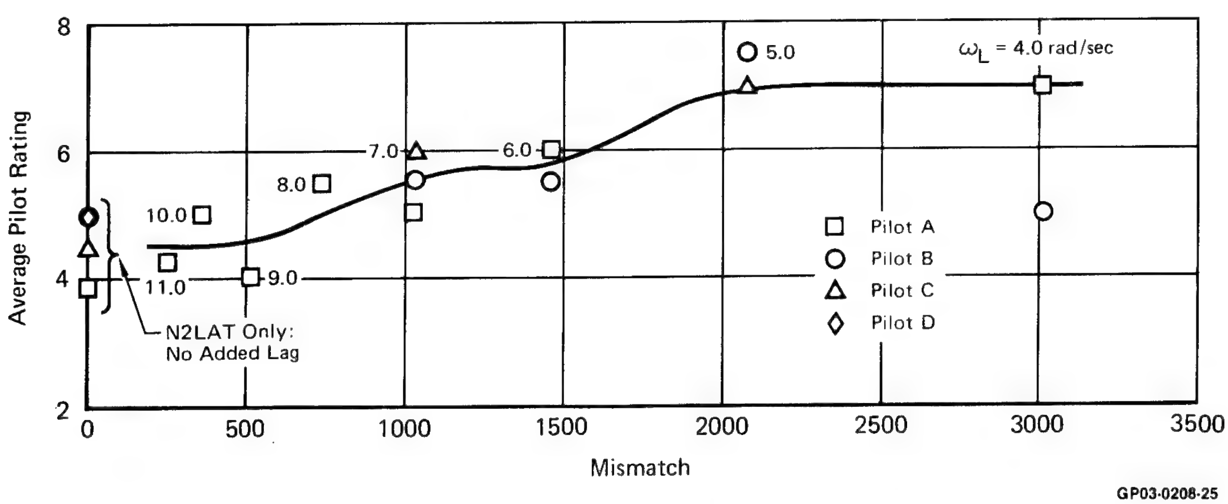

Figure 24. Comparison of Average Pilot Rating and Mismatch for a 2nd Order Lag Added to N2LAT

Match Frequency Range: 0.5 - 10 Rad/Sec

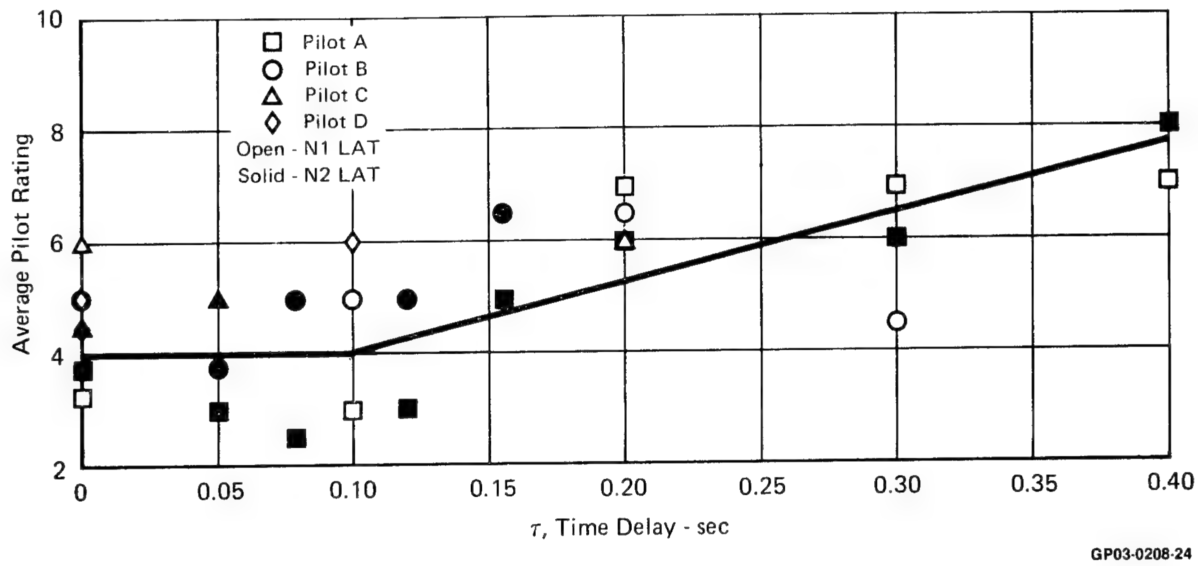

Figure 25. Effect of Pure Time Delay on Pilot Rating
Ratings from Both Nominal Systems

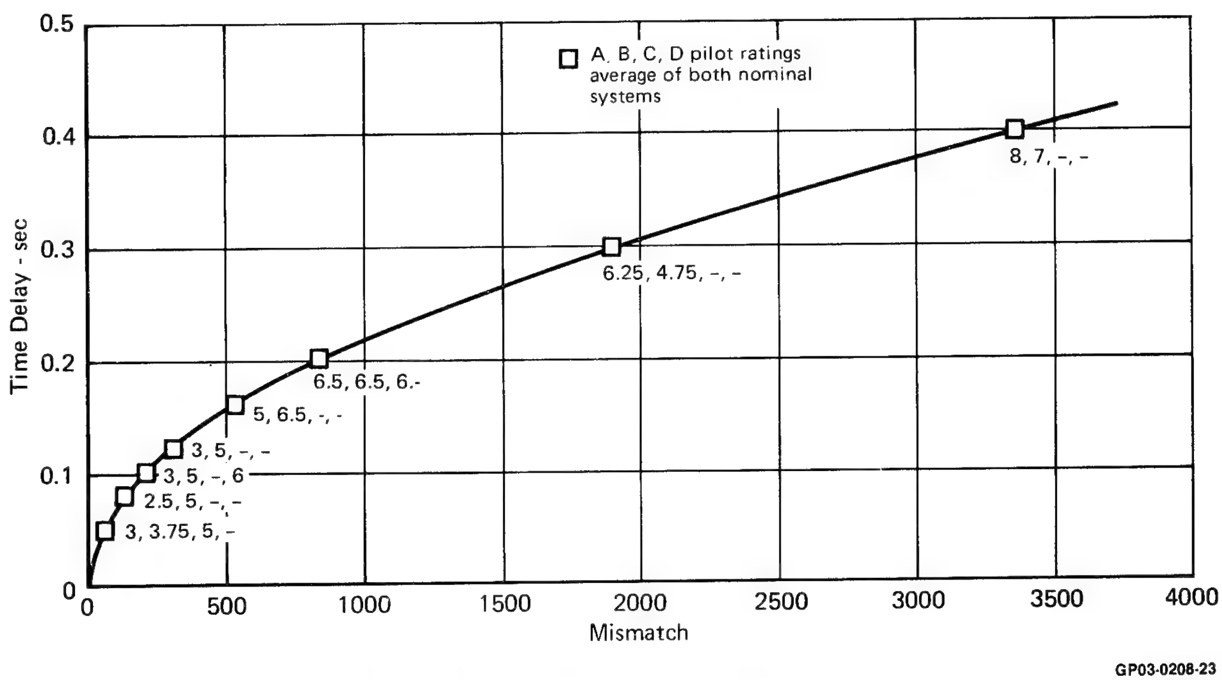

Figure 26. Effect of Time Delay on Mismatch
Match Range: 0.5-10 Rad/Sec

To gather data in this area, pure time delay was added to N1LAT and N2LAT. The time delay added to N2LAT produced the same amount of phase lag at its nominal frequency as was produced for N1LAT at its nominal frequency as described in Section II-9-c.

Table 3 presents the time delay and phase lag values explored. Pilot rating versus phase angle is presented in Figure 27. The data show a rating degradation with lag but the pilot rating for a given lag is worse (larger) for the configuration with the lower natural frequency. Since a given delay produces a larger phase lag at a higher natural frequency, the rating is more likely a function of delay, not lag.

7. HIGH ORDER FLIGHT PATH DYNAMICS - The question of whether pilots desire low order attitude responses has been answered in Sections III-4, 5 and 6. Some configurations were evaluated to determine whether the results were dependent on the flight path characteristics. As is pointed out in Reference 1, there is an interaction between attitude and flight path dynamics which can result in high-order-appearing responses and degraded ratings.

The nominal lateral flight path bandwidth, Y_v, value was -.1 which was used through the majority of the simulation. A few representative runs were made with $Y_v = -.2$. The data indicate the pilot did not notice any type of degradation or improvement in the aircraft handling with the change in Y_v. Because of this result, the two data sets are combined with no distinction between the two. The configurations which were run with $Y_v = -.2$ are distinguished in the listing in Appendix B. Time did not permit further investigation of different Y_v values.

8. EFFECT OF COMMAND GAIN/TIME DELAY INTERACTIONS - The effects on pilot rating of a variation in command gain and time delay for N1LAT are shown in Figure 28. Command gains investigated were .079, .118, .177 (nominal), .236, .315 and .394 rad/cm with time delay varying from 0.0 to .4 sec.

Figure 28 shows that low gain (.079) causes a rating of 7 with no degradation due to time delay. Pilot comments showed that with low gain, the task required a large workload regardless of delay.

For a high gain (.394), the baseline dynamics were excellent but time delay produced an immediate degradation in pilot rating. The addition of only 0.1 sec time delay degraded the rating from 2.5 to 6. Further addition of time delay to the high gain case eventually caused loss of control.

With a high gain, the pilot was unable to detach himself from the task and time delay produced a sharp degradation in pilot rating. Ratings of low command gains were affected less by added time delay; the ratings remained poor. Up to 0.2 sec time delay can be tolerated in moderate command gain situations. This trend is also evident in CTOL data (Reference 8).

TABLE 3. TIME DELAY vs PHASE LAG

Summary of Results

τ	ω_n	ϕ^o	Pilot Rating
0.1	2.0 (N1LAT)	11.46	3, 5, 6
0.2	↓	22.92	6.5, 6.5, 7
0.3	↓	34.38	4.75, 6.25
0.4	↓	45.84	8, 7
0.05	5.0 (N2LAT)	14.33	3, 3.75, 5
0.08	↓	22.92	2.5, 5
0.12	↓	34.38	3, 5
0.16	↓	45.84	6.5, 5

$\phi = \omega_n \tau\ (57.3)$

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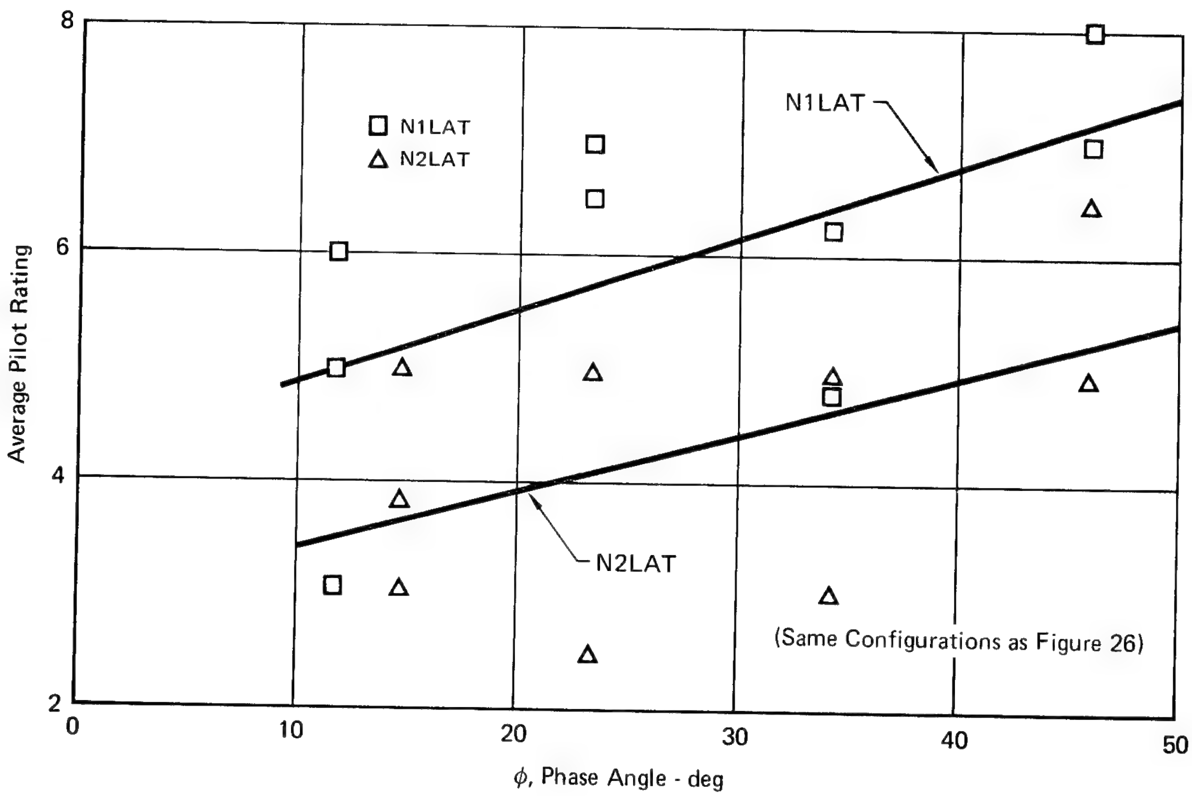

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Figure 27. Effect of Phase Lag on Average Pilot Rating

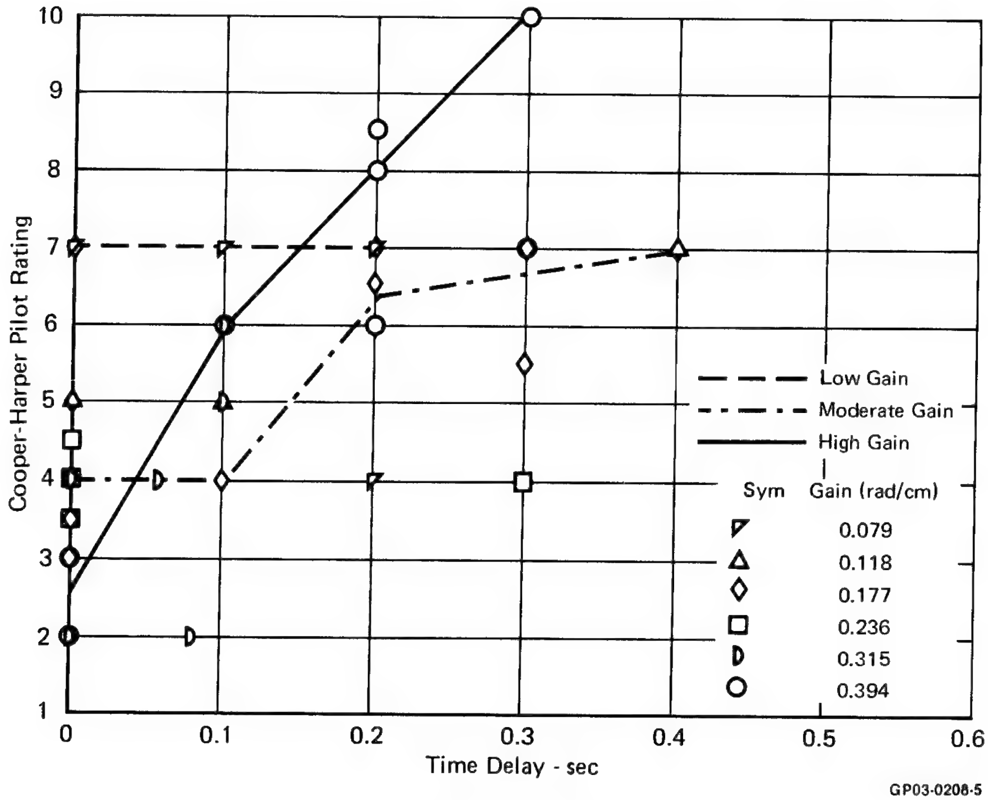

Figure 28. Interaction of Command Gain and Time Delay
Baseline Dynamics: [0.7; 2.0]

Figure 29 presents the same data as a set of curves for increasing time delay. This shows the expected U-shaped rating variation with gain as the gain progresses from insensitivity, through optimum, to oversensitivity.

9. EQUIVALENT SYSTEMS ANALYSIS OF HIGH FREQUENCY EFFECTS - As stated in Reference 1, a large class of attitude augmented VTOL's possess attitude dynamics which can be approximated by:

$$\frac{Ke^{-\tau_e s}}{s^2 + 2\zeta_e\omega_e s + \omega_e^2}$$

This function was matched in the frequency range of 0.1 to 10.0 rad/sec to each high order configuration generated by adding high frequency lags or delays to N1LAT and N2LAT. The parameter τ_e is an equivalent time delay which chiefly approximates the phase lag contribution of the high frequency first and second order elements in the high order system. The results appear in Table 4. The great majority of cases were matched quite closely. Figure 30 presents average pilot rating versus τ_e. The shaded areas represent the three levels of flying qualities. The time delay boundaries for these areas were determined from the results of the transport lag (actual time delay) variation of Figure 25. The equivalent time delay data fall mostly within these transport lag boundaries, tending to validate equivalent delay as a flying qualities parameter. The data which lie outside the boundaries are good matches and, like all the equivalents, possess Level 1 gain values. However, they are borderline Level 1 according to the ω_n vs. $2\zeta_n\omega_n$ criteria established in Reference 1. This together with the additional flying qualities degradation due to equivalent time delay puts these data in Levels 2 and 3.

These data show that the total equivalent configuration (ζ_e, ω_e, τ_e, K) must be assessed very carefully. Even though each element of the equivalent configuration may meet its Level 1 criterion, the total equivalent configuration may not be Level 1. A cautionary note on this 'multiple degradation' effect should be included in any formal specification of VTOL flying qualities.

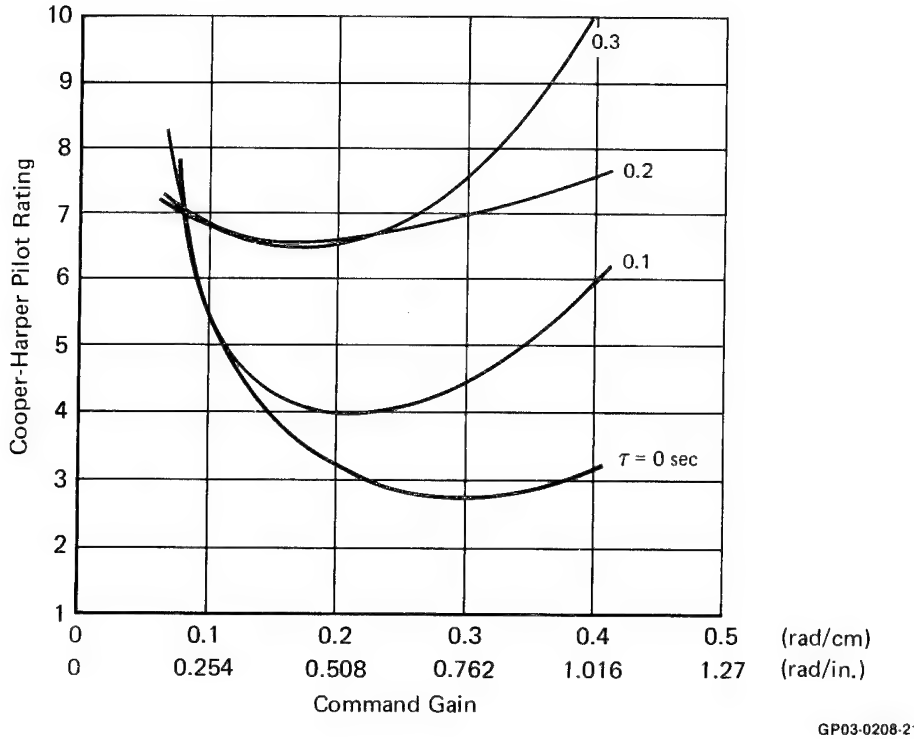

Figure 29. Variation of Pilot Rating with Command Gain and Time Delay

TABLE 4. EQUIVALENT SYSTEMS PARAMETERS

Configuration	HOS			LOS				Average Pilot Rating
	ζ	ω	λ	ζ	ω	τ	Mis-Match	
HF111	0.7	2	1	0.4793	1.0869	0.1585	159.0	7.5
HF112	0.7	2	2	0.4791	1.3499	0.1424	98.9	6.25
HF113	0.7	2	3	0.5039	1.5091	0.1290	63.4	4.8
HF114	0.7	2	4	0.5312	1.6166	0.1176	41.9	5.5, 4
HF115	0.7	2	5	0.5560	1.6938	0.1078	28.4	3.5, 6
HF116	0.7	2	6	0.5773	1.7511	0.0993	19.7	5, 4.5, 5
HF117	0.7	2	7	0.5951	1.7948	0.0919	14	4.5
HF211	0.7	5	1	0.9776	1.9995	0.1105	24.6	5.8
HF212	0.7	5	2	0.7826	2.6636	0.1022	17.1	3.25
HF213	0.7	5	3	0.7146	3.1080	0.0950	12	3.25
HF214	0.7	5	4	0.6853	3.4351	0.0887	8.55	3, 3.5
HF215	0.7	5	5	0.6722	3.6874	0.0830	6.17	3, 3.75
HF216	0.7	5	6	0.6669	3.8871	0.0779	4.51	3, 4
HF217	0.7	5	7	0.6654	4.0481	0.0733	3.35	3, 5
HF124	0.7	2	–	0.3722	1.9622	0.3113	453	6, 6.75
	0.3	4						
HF125	0.7	2	–	0.4992	2.1550	0.2847	256	6, 6, 7.5
	0.3	5						
HF126	0.7	2	–	0.6295	2.3167	0.2589	135	5.5, 4
	0.3	6						
HF127	0.7	2	–	0.7525	2.4422	0.2330	65.9	6.5, 5.5
	0.3	7						
HF128	0.7	2	–	0.8511	2.5136	0.2061	32.0	4.5
	0.3	8						
HF129	0.7	2	–	0.9058	2.5135	0.1777	18.9	3.75
	0.3	9						
HF120	0.7	2	–	0.9122	2.4519	0.1492	15.4	4.25
	0.3	10						
HF121	0.7	2	–	0.8888	2.3680	0.1237	13.8	5
	0.3	11						
HF224	0.7	5	–	0.2534	3.3367	0.2386	126	7
	0.3	4						
HF225	0.7	5	–	0.2935	3.9785	0.2270	90.6	7, 8, 7
	0.3	5						
HF226	0.7	5	–	0.3474	4.5775	0.2152	60	6, 5.5
	0.3	6						
HF227	0.7	5	–	0.4139	5.1556	0.2034	36.1	5, 5.5, 6
	0.3	7						
HF228	0.7	5	–	0.4914	5.7226	0.1915	19.1	5.5
	0.3	8						
HF229	0.7	5	–	0.5757	6.2526	0.1787	8.8	4
	0.3	9						
HF220	0.7	5	–	0.6565	6.6474	0.1640	3.71	5
	0.3	10						
HF221	0.7	5	–	0.7165	6.7795	0.1466	1.84	4.25
	0.3	11						

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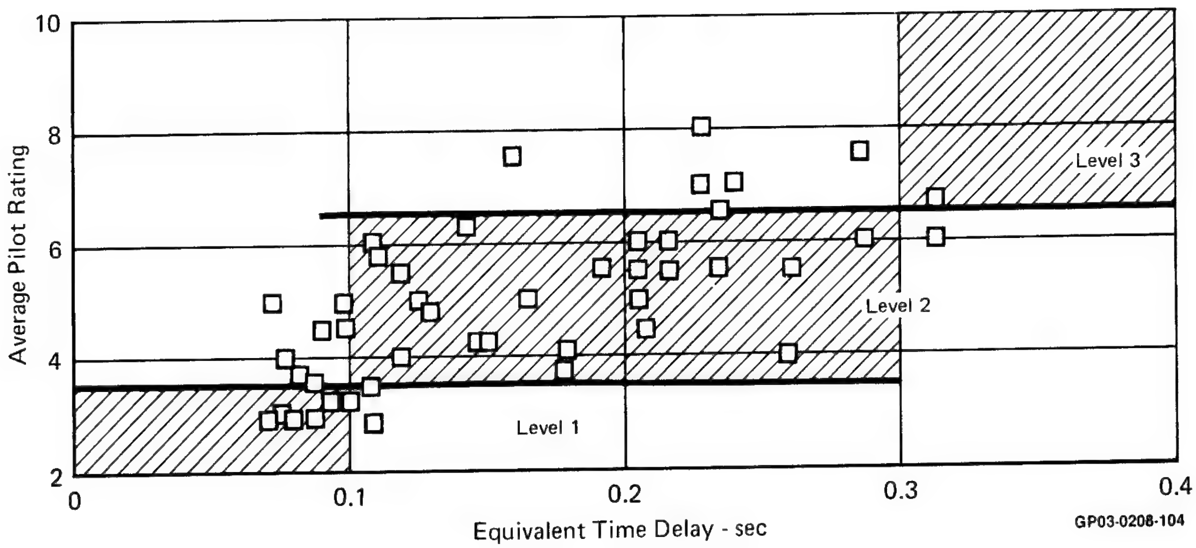

Figure 30. Variation of Average Pilot Rating with Equivalent Time Delay

IV SUMMARY AND CONCLUSIONS

A fixed-base simulation of attitude-type V/STOL dynamics in hovering and low speed flight was conducted. By adding high order effects to two nominal bank angle dynamic models, information was gained on allowable mismatches between high order and low order systems. The results show that it is reasonable to specify high order V/STOL dynamics in terms of low order equivalent system parameters. Mismatch levels for analytically derived equivalents will normally be far below the values of mismatch shown in this experiment to be noticeable to pilots. The general objective of gaining information on equivalents was tackled by asking four related questions. These are asked, and their answers given, below.

(1) <u>What is an allowable mismatch between the high order system and its low order equivalent?</u>

(2) <u>What is the pilot's frequency range of interest?</u>

Since mismatch is a function of frequency range, these questions are answered jointly.

The lower end of the frequency range was explored by adding two types of dynamics to the nominal systems. The first was a poorly damped mode with a low frequency gain roll-off and the second was a localized notch in the frequency response. Pilot comments indicated that both these high order effects ultimately degraded the nominal dynamics by reducing low frequency gain, or control effectiveness. The roll-off produced steadily decreasing gain, with zero steady state gain, and the notch produced a localized reduction of about 10dB. The flying qualities degradation due to the low frequency dynamics occurred when:

(i) the local gain mismatch reached 10 dB in the frequency range .1 to .3 rad/sec (Figure A-24)

(ii) similarly, a mismatch value of 400. due to low frequency effects alone was exceeded in the frequency range .1 to 10 rad/sec (Figure 16)

(iii) a mismatch value of 100. was reached in the frequency range .5 to 10 rad/sec

Matching from .5 to 10 rad/sec is a way of de-emphasizing low frequency modes, i.e a way of weighting the response match more towards the crossover region of piloted control.

The upper end of the pilot's frequency range was explored by adding one of three types of dynamics to the nominal systems; a first order lag, a second order lag, or a pure time delay. Values

of break frequency, natural frequency, and pure delay were established which caused a degradation in pilot rating.

The degradation due to the high frequency dynamics appeared when:

(i) the local phase mismatch reached 20. degrees in the frequency range 4.0 to 10 rad/sec. (Figure A-17)

(ii) similarly, a mismatch value of 260. due to high frequency effects alone was exceeded in the frequency range .1 to 10 rad/sec

(iii) a mismatch value of 15. was reached in the frequency range .1 to 4 rad/sec

Matching from .1 to 4. rad/sec is a way of de-emphasizing high frequency modes, i.e. a way of weighting the response match more towards the crossover region of piloted control. From the foregoing, it is evident that the pilot's frequency range of interest can be defined as a tentative envelope of mismatch (Figure 31). This figure can be interpreted in two ways:

(a) When a second order frequency response match to an attitude system has been obtained, the gain and phase mismatches at each frequency should be less than Figure 31. Caution should be exercised in using the envelope to interpret high order modes which differ from those used in this present study.

(b) The envelope can be used to establish a weighting of gain and phase match as a function of frequency.

This range, as might be expected, is broadly the crossover region for piloted control. However, recent data suggest that some piloting tasks demand a higher crossover frequency than 4 rad/sec. The possibility of a higher crossover frequency for actual landing has been taken into account in establishing the above limits, however, caution should be exercised by allowing a reasonable margin of lag at higher frequencies.

(3) <u>Do pilots require low-order-appearing responses in attitude, velocity and position to control inputs, and will they reject more complicated high order responses?</u>

It was shown from the pilot comments and ratings that handling qualities were degraded when high order effects were introduced into the pilot's frequency range of interest. This is described in detail in the answer to the first two questions.

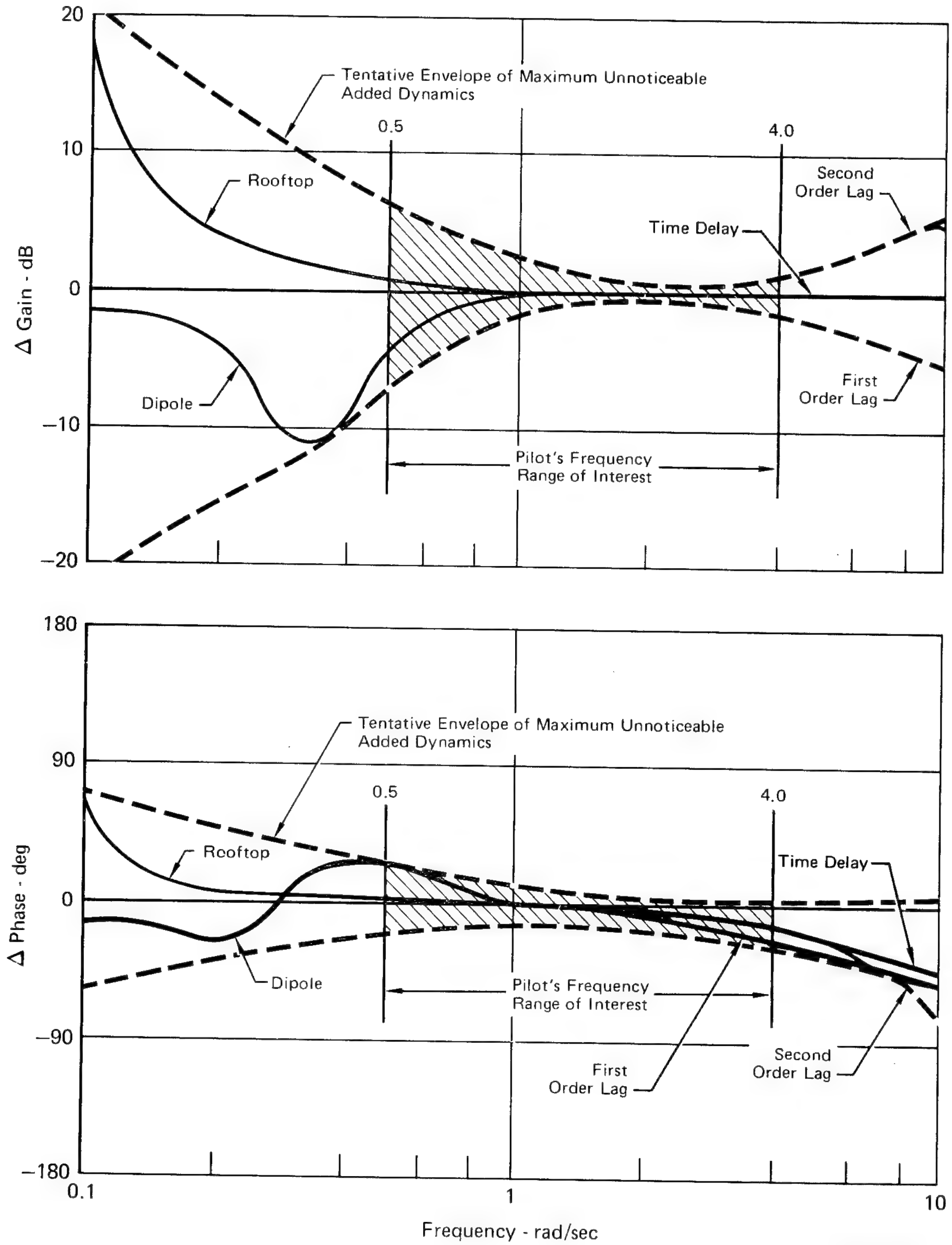

Figure 31. Summary of Maximum Augmentation Added Without Affecting Rating

(4) <u>What are the piloting effects of time delay versus the effects of phase lag?</u>

By using two nominal system natural frequencies and judiciously chosen time delays, it was shown that pilots key more on the amount of pure time delay than on the amount of phase lag produced at the natural frequencies. Therefore, phase lag at the natural frequency is less suitable as a specification parameter. Time delay values of .10 and .30 second are suitable maxima for Levels 1 and 2.

V RECOMMENDATIONS

(1) The conclusions of this study for hover and for low speed dynamics should be reexamined for the transition flight regime.

(2) This present study focused on the flying qualities of attitude type dynamics. Examination of translation rate and other advanced systems should also be pursued.

(3) The effects of command gain on the flying qualities degradation due to time delay should be explored. Ideally, a rule should be established for command gain in a ground-based simulation which will produce identical pilot rating degradation as that seen in actual flight.

(4) This present study maintained excellent longitudinal characteristics while varying the lateral dynamics. The effects of degrading longitudinal and lateral dynamics simultaneously need evaluation.

(5) The equivalent system tolerance rules (Figure 31) which have been established by this study should be incorporated in a computer program. A particularly suitable program feature would be to weight the mismatch as a function of frequency to stress the crossover region.

(6) In future simulations, a stronger height cue would aid the pilot and compensate for the runway texture and other cues which are available in actual flight. A well-displayed analog HUD display of vertical situation should be adequate.

(7) Verification of these and similar results in a flight test (variable-stability machine) with extension of the task to touchdown will be highly desirable.

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APPENDIX A

CONFIGURATION DATA

A listing of each configuration is given accompanied by individual pilot ratings. The roots and coefficients of the transfer functions are listed separately. A configuration key is also presented. Frequency responses and time responses to a unit step input are presented for the nominal systems versus the HOS.

The frequency responses are shown on the same scale to allow overlaying data. The time responses are also on the same scale, with the exception of the gain variation cases (G-).

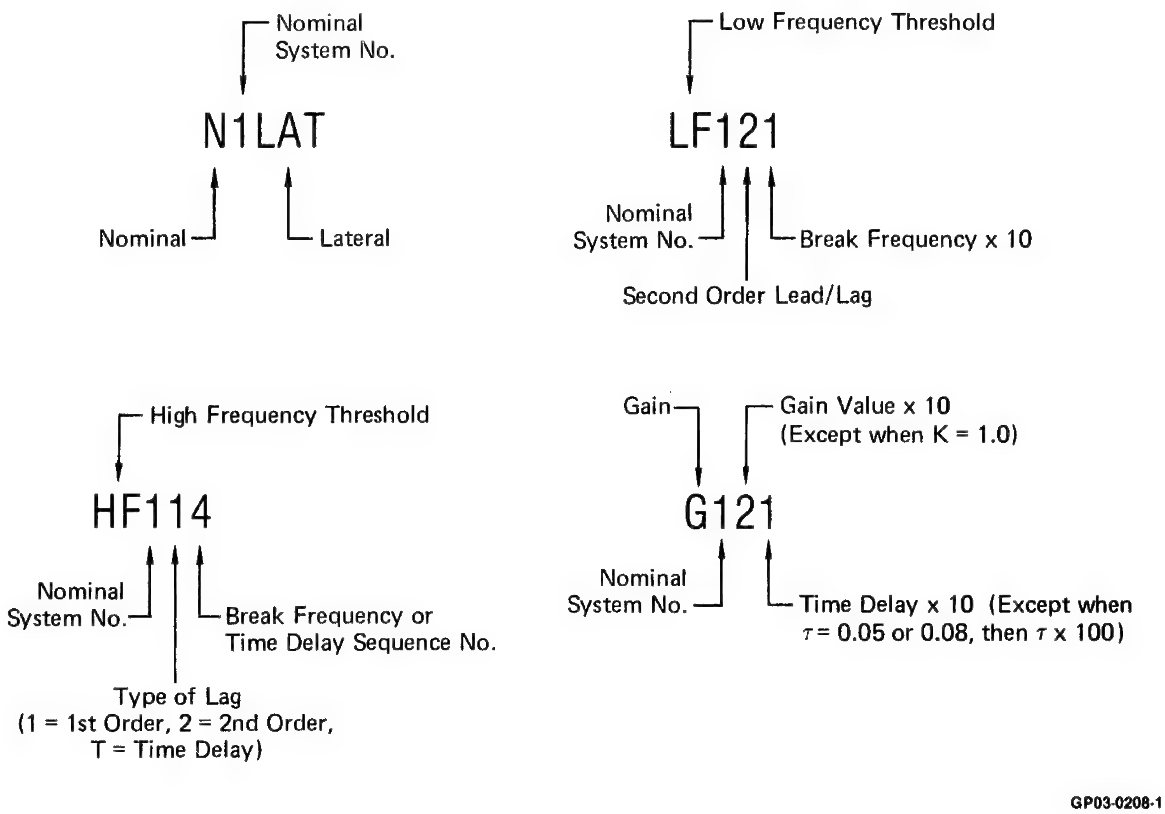

Figure A-1. Key to Configuration Listing

	Nominal			Nuisance Mode					Pilot Rating			
Config	Gain	ζ	ω_n	τ (Equiv ϕ)	λ	ζ_N	ζ_D	ω_L or DP	A	B	C	D
N1LAT	0.6	0.7	2.0	–	–	–	–	–		4.5,4,3.5		4,7,4
	0.45			–	–	–	–	–	4,4,4,4,3,3,3,2,3, 3,3,3,4,3,3,3,2,2, 5,4	3.5,3,4,3.5 3.5	7,5	
	0.3			–	–	–	–	–		3.5,5		3
N2LAT	0.3		5.0	–	–	–	–	–	4,4,4,4,5,3,3,3,3, 3,3,5,4,4,5,4,3,	6.5,5,3.5,5 5,5	5,4	5
HF111	0.45		2.0	–	1.0	–	–	–	7,7,9,7			
HF112				–	2.0	–	–	–	5,8,6,6			
HF113				–	3.0	–	–	–	6,4,3,5,6			
HF114	0.6			–	4.0	–	–	–		4		
	0.45			–		–	–	–	5,6			
HF115	0.3			–	5.0	–	–	–		3.5		
	0.45			–		–	–	–	5,4		6	
HF116	0.6			–	6.0	–	–	–				5
	0.45			–		–	–	–	5	4.5		
HF117	0.3			–	7.0	–	–	–		4.5		
HF124	0.6			–	–	–	0.3	4.0		6		
	0.45			–	–	–			6	7.5		
HF125	0.6			–	–	–		5.0				7.5
	0.45			–	–	–			5	6		
	0.3			–	–	–			6			
HF126	0.45			–	–	–		6.0	6,5	4,4		
HF127				–	–	–		7.0	7,6			
	0.3			–	–	–				5.5		
HF128	0.45			–	–	–		8.0	4,5			
HF129				–	–	–		9.0	3,4,4,4			
HF120				–	–	–		10.0	5,5,3,4			
HF121				–	–	–		11.0	6,4,5			

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Figure A-2. List of Configurations and Pilot Ratings

	Nominal			Nuisance Mode					Pilot Rating			
Config	Gain	ζ	ω_n	τ (Equiv ϕ)	λ	ζ_N	ζ_D	ω_L or DP	A	B	C	D
HF1T1	0.6	0.7	2.0	0.1 (11.46°)	–	–	–	–				6
	0.45				–	–	–	–	4,2			
	0.3				–	–	–	–		5		
HF1T2	0.45			0.2 (22.92°)	–	–	–	–	7,7	6.5	6	
HF1T3	0.6			0.3 (34.38°)	–	–	–	–		4		
	0.45				–	–	–	–	7	5.5		
HF1T4	0.3			0.4 (45.84°)	–	–	–	–		7		
	0.45				–	–	–	–	7			
LF121	0.45			–	–	0.2	0.7	0.1	3		4	
LF123				–	–			0.3	2,3			
LF125				–	–			0.5	3,4			
LF127				–	–			0.7	4,7		8	
LF121*	0.6			–	–	–	0.05	0.1				3
LF123*				–	–	–		0.3				7
LF125*				–	–	–		0.5				10
LF127*				–	–	–		0.7				10
HF211	0.3		5.0	–	1.0	–	–	–	6,6,5,6,6			
HF212				–	2.0	–	–	–	2,3,3,5			
HF213				–	3.0	–	–	–	3,4,3,3			
HF214				–	4.0	–	–	–	3	3.5		
HF215				–	5.0	–	–	–	3	3,4.5	5	
HF216				–	6.0	–	–	–	3	4		
HF217				–	7.0	–	–	–	3		5	
HF224				–	–	–	0.3	4.0	7	5		
HF225				–	–	–		5.0		7,8	7	
HF226				–	–	–		6.0	6,6	5.5		
HF227				–	–	–		7.0	6	5,6	6	
HF228				–	–	–		8.0	8,4,4,6			
HF229				–	–	–		9.0	5,4,3			
HF220				–	–	–		10.0	4,8,3			

*Exaggerated rooftop systems

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Figure A-2. (Continued) List of Configurations and Pilot Ratings

	Nominal			Nuisance Mode					Pilot Rating			
Config	Gain	ζ	ω_n	τ (Equiv ϕ)	λ	ζ_N	ζ_D	ω_L or DP	A	B	C	D
HF221	0.3	0.7	5.0	–	–	–	0.3	11.0	7,4,2,4			
HF2T1				0.05 (14.33°)	–	–	–	–	3	3,4.5	5	
HF2T2				0.08 (22.92°)	–	–	–	–	2,3	5		
HF2T3				0.12 (34.38°)	–	–	–	–	3	5		
HF2T4				0.16 (45.84°)	–	–	–	–	5,5,5,5	6.5		
HF2T5				0.2	–	–	–	–	6,6			
HF2T6				0.3	–	–	–	–	8,5,5			
HF2T7				0.4	–	–	–	–	8,9			
LF221				–	–	0.2	0.7	0.1	3			
LF223				–	–			0.3	4		8	
LF225				–	–			0.5	6			
LF227				–	–			0.7	6			
LF221*				–	–	–	0.05	0.1				5
LF223*				–	–	–		0.3				
LF225*				–	–	–		0.5				
LF227*				–	–	–		0.7				
G110	1.0		2.0	0 (0°)	–	–	–	–	3, 2, 3, 2			
G111				0.1 (11.46°)	–	–	–	–	6,6			
G112				0.2 (22.92°)	–	–	–	–	8.5, 8, 7	6		
G113				0.3 (34.38°)	–	–	–	–	7	10		
G120	0.2			0 (0°)	–	–	–	–	7,7			
G121				0.1 (11.46°)	–	–	–	–	7,7			
G122				0.2 (22.92°)	–	–	–	–	7,7,4	7		
G180	0.8			0 (0°)	–	–	–	–	2,4			
G186				0.06 (6.88°)	–	–	–	–	4,4			
G188				0.08 (9.168°)	–	–	–	–	2,2			
G181				0.1 (11.46°)	–	–	–	–	6,5			

*Exaggerated rooftop systems

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FigureA-2. (Concluded) List of Configurations and Pilot Ratings

Configuration	Transfer Function	Description
N1LAT	$\frac{0.45}{0.25S^2 + 0.7S + 1.0}$	Nominal System No. 1 [0.7; 2.0]
N2LAT	$\frac{0.3}{0.04S^2 + 0.28S + 1.0}$	Nominal System No. 2 [0.7; 5.0]
	High Frequency Threshold	
HF111	$\frac{0.45}{0.25S^3 + 0.95S^2 + 1.7S + 1.0}$	N1LAT $\frac{1}{(1.0)}$
HF112	$\frac{0.45}{0.125S^3 + 0.6S^2 + 1.2S + 1.0}$	N1LAT $\frac{1}{(2.0)}$
HF113	$\frac{0.45}{0.083S^3 + 0.483S^2 + 1.03S + 1.0}$	N1LAT $\frac{1}{(3.0)}$
HF114	$\frac{0.45}{0.0625S^2 + 0.425S^2 + 0.95S + 1.0}$	N1LAT $\frac{1}{(4.0)}$
HF115	$\frac{0.45}{0.05S^3 + 0.39S^2 + 0.9S + 1.0}$	N1LAT $\frac{1}{(5.0)}$
HF116	$\frac{0.45}{0.0417S^3 + 0.367S^2 + 0.867S + 1.0}$	N1LAT $\frac{1}{(6.0)}$
HF117	$\frac{0.45}{0.0357S^3 + 0.35S^2 + 0.843S + 1.0}$	N1LAT $\frac{1}{(7.0)}$
HF124	$\frac{0.45}{0.016S^4 + 0.081S^3 + 0.418S^2 + 0.85S + 1.0}$	N1LAT $\frac{1}{[0.3; 4.0]}$
HF125	$\frac{0.45}{0.01S^4 + 0.058S^3 + 0.374S^2 + 0.82S + 1.0}$	N1LAT $\frac{1}{[0.3; 5.0]}$
HF126	$\frac{0.45}{0.007S^4 + 0.044S^3 + 0.348S^2 + 0.8S + 1.0}$	N1LAT $\frac{1}{[0.3; 6.0]}$
HF127	$\frac{0.45}{0.005S^4 + 0.036S^3 + 0.33S^2 + 0.786S + 1.0}$	N1LAT $\frac{1}{[0.3; 7.0]}$
HF128	$\frac{0.45}{0.0039S^4 + 0.029S^3 + 0.318S^2 + 0.775S + 1.0}$	N1LAT $\frac{1}{[0.3; 8.0]}$

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Figure A-3. List of Configuration Transfer Functions

Configuration	Transfer Function	Description
	High Frequency Threshold	
HF129	$\frac{0.45}{0.0031S^4 + 0.25S^3 + 0.309S^2 + 0.767S + 1.0}$	N1LAT $\frac{1}{[0.3; 9.0]}$
HF120	$\frac{0.45}{0.0025S^4 + 0.022S^3 + 0.302S^2 + 0.76S + 1.0}$	N1LAT $\frac{1}{[0.3; 10.0]}$
HF121	$\frac{0.45}{0.0021S^4 + 0.019S^3 + 0.296S^2 + 0.755S + 1.0}$	N1LAT $\frac{1}{[0.3; 11.0]}$
HF1T1	$\frac{0.45e^{-0.1S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT ($\tau = 0.1$)
HF1T2	$\frac{0.45e^{-0.2S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT ($\tau = 0.2$)
HF1T3	$\frac{0.45e^{-0.3S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT ($\tau = 0.3$)
HF1T4	$\frac{0.45e^{-0.4S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT ($\tau = 0.4$)
HF211	$\frac{0.3}{0.04S^3 + 0.32S^2 + 1.28S + 1.0}$	N2LAT $\frac{1}{(1.0)}$
HF212	$\frac{0.3}{0.02S^3 + 0.18S^2 + 0.78S + 1.0}$	N2LAT $\frac{1}{(2.0)}$
HF213	$\frac{0.3}{0.013S^3 + 0.133S^2 + 0.613S + 1.0}$	N2LAT $\frac{1}{(3.0)}$
HF214	$\frac{0.3}{0.1S^3 + 0.11S^2 + 0.53S + 1.0}$	N2LAT $\frac{1}{(4.0)}$
HF215	$\frac{0.3}{0.008S^3 + 0.96S^2 + 0.48S + 1.0}$	N2LAT $\frac{1}{(5.0)}$
HF216	$\frac{0.3}{0.007S^3 + 0.87S^2 + 0.447S + 1.0}$	N2LAT $\frac{1}{(6.0)}$

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Figure A-3. (Continued) List of Configuration Transfer Functions

Configuration	Transfer Function	Description
	High Frequency Threshold	
HF217	$\frac{0.3}{0.006S^3 + 0.8S^2 + 0.423S + 1.0}$	$N2LAT \frac{1}{(7.0)}$
HF224	$\frac{0.3}{0.003S^4 + 0.024S^3 + 0.145S^2 + 0.43S + 1.0}$	$N2LAT \frac{1}{[0.3; 4.0]}$
HF225	$\frac{0.3}{0.002S^4 + 0.016S^3 + 0.114S^2 + 0.4S + 1.0}$	$N2LAT \frac{1}{[0.3; 5.0]}$
HF226	$\frac{0.3}{0.001S^4 + 0.012S^3 + 0.096S^2 + 0.38S + 1.0}$	$N2LAT \frac{1}{[0.3; 6.0]}$
HF227	$\frac{0.3}{0.0008S^4 + 0.009S^3 + 0.084S^2 + 0.366S + 1.0}$	$N2LAT \frac{1}{[0.3; 7.0]}$
HF228	$\frac{0.3}{0.000625S^4 + 0.00738S^3 + 0.0766S^2 + 0.355S + 1.0}$	$N2LAT \frac{1}{[0.3; 8.0]}$
HF229	$\frac{0.3}{0.000494S^4 + 0.0061S^3 + 0.071S^2 + 0.347S + 1.0}$	$N2LAT \frac{1}{[0.3; 9.0]}$
HF220	$\frac{0.3}{0.0004S^4 + 0.0052S^3 + 0.0668S^2 + 0.34S + 1.0}$	$N2LAT \frac{1}{[0.3; 10.0]}$
HF221	$\frac{0.3}{0.000331S^4 + 0.0045S^4 + 0.0635S^2 + 0.335S + 1.0}$	$N2LAT \frac{1}{[0.3, 11.0]}$
HF2T1	$\frac{0.3e^{-0.05}}{0.04S^2 + 0.28S + 1.0}$	N2LAT ($\tau = 0.05$)
HF2T2	$\frac{0.3e^{-0.08S}}{0.04S^2 + 0.28S + 1.0}$	N2LAT ($\tau = 0.08$)
HF2T3	$\frac{0.3e^{-0.12S}}{0.04S^2 + 0.28S + 1.0}$	N2LAT ($\tau = 0.12$)
HF2T4	$\frac{0.3e^{-0.16S}}{0.04S^2 + 0.28S + 1.0}$	N2LAT ($\tau = 0.16$)

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Figure A-3. (Continued) List of Configuration Transfer Functions

Configuration	Transfer Function	Description
	High Frequency Threshold	
HF2T5	$\dfrac{0.3e^{-0.2S}}{0.04S^2 + 0.28S + 1.0}$	N2LAT ($\tau = 0.2$)
HF2T6	$\dfrac{0.3e^{-0.3S}}{0.04S^2 + 0.28S + 1.0}$	N2LAT ($\tau = 0.3$)
HF2T7	$\dfrac{0.3e^{-0.4S}}{0.04S^2 + 0.28S + 1.0}$	N2LAT ($\tau = 0.4$)
	Low Frequency Threshold	
LF121:	$\dfrac{45.0S^2 + 1.8S + 0.45}{25.0S^4 + 73.5S^3 + 110.05S^2 + 14.7S + 1.0}$	N1LAT $\dfrac{[0.2; 0.1]}{[0 7; 0.1]}$
LF123:	$\dfrac{5.0S^2 + 0.6S + 0.45}{2.78S^4 + 8.94S^3 + 14.63S^2 + 5.37S + 1.0}$	N1LAT $\dfrac{[0.2; 0.3]}{[0.7; 0.3]}$
LF125:	$\dfrac{1.8S^2 + 0.36S + 0.45}{1.0S^4 + 3.5S^3 + 6.21S^2 + 3.5S + 1.0}$	N1LAT $\dfrac{[0.2; 0.5]}{[0.7; 0.5]}$
LF127:	$\dfrac{0.92S^2 + 0.26S + 0.45}{0.51S^4 + 1.93S^3 + 3.69S^2 + 2.7S + 1.0}$	N1LAT $\dfrac{[0.2; 0.7]}{[0.7; 0.7]}$
LF221:	$\dfrac{30.0S^2 + 1.2S + 0.3}{4.0S^4 + 28.56S^3 + 103.96S^2 + 14.28S + 1.0}$	N2LAT $\dfrac{[0.2; 0.1]}{[0.7; 0.1]}$
LF223:	$\dfrac{3.33S^2 + 0.4S + 0.3}{0.44S^4 + 3.3S^3 + 12.46S^2 + 4.95S + 1.0}$	N2LAT $\dfrac{[0.2; 0.3]}{[0.7; 0.3]}$
LF225:	$\dfrac{1.2S^2 + 0.24S + 0.3}{0.16S^4 + 1.23S^3 + 4.82S^2 + 3.08S + 1.0}$	N2LAT $\dfrac{[0.2; 0.5]}{[0.7; 0.5]}$
LF227:	$\dfrac{0.61S^2 + 0.17S + 0.3}{0.082S^4 + 0.65S^3 + 2.64S^2 + 2.28S + 1.0}$	N2LAT $\dfrac{[0.2; 0.7]}{[0.7; 0.7]}$

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Figure A-3. (Continued) List of Configuration Transfer Functions

Configuration	Transfer Function	Description
LF121*	$\dfrac{0.45S^2}{25.S^4 + 70.25S^3 + 100.95S^2 + 1.7S + 1.0}$	N1LAT $\dfrac{S^2}{[0.05; 0.1]}$
LF123*	$\dfrac{0.45S^2}{2.778S^4 + 7.86S^3 + 11.59S^2 + 1.033S + 1.0}$	N1LAT $\dfrac{S^2}{[0.05; 0.3]}$
LF125*	$\dfrac{0.45S^2}{S^4 + 2.85S^3 + 4.39S^2 + 0.9S + 1.0}$	N1LAT $\dfrac{S^2}{[0.05; 0.5]}$
LF127*	$\dfrac{0.45S^2}{0.51S^4 + 1.464S^3 + 2.39S^2 + 0.843S + 1.0}$	N1LAT $\dfrac{S^2}{[0.05; 0.7]}$
LF221*	$\dfrac{0.3S^2}{4S^4 + 28.04S^3 + 100.32S^2 + 1.28S + 1.0}$	N2LAT $\dfrac{S^2}{[0.05; 0.1]}$
LF223*	$\dfrac{0.3S^2}{0.444S^4 + 3.124S^3 + 11.243S^2 + 0.613S + 1.0}$	N2LAT $\dfrac{S^2}{[0.05; 0.3]}$
LF225*	$\dfrac{0.3S^2}{0.16S^4 + 1.128S^3 + 4.096S^2 + 0.48S + 1.0}$	N2LAT $\dfrac{S^2}{[0.05; 0.5]}$
LF227*	$\dfrac{0.3S^2}{0.0816S^4 + 0.5769S^3 + 2.12S^2 + 0.423S + 1.0}$	N2LAT $\dfrac{S^2}{[0.05; 0.7]}$

*Exaggerated rooftop systems.

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Figure A-3. (Continued) List of Configuration Transfer Functions

Configuration	Transfer Function	Description
	Effect of Gains	
G120	$\frac{0.2}{0.25S^2 + 0.7S + 1.0}$	N1LAT (τ = 0, K = 0.2)
G121	$\frac{0.2e^{-0.1S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT (τ = 0.1, K = 0.2)
G122	$\frac{0.2e^{-0.2S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT (τ = 0.2, K = 0.2)
G110	$\frac{1.0}{0.25S^2 + 0.7S + 1.0}$	N1LAT (τ = 0, K = 1.0)
G111	$\frac{1.0e^{-0.1S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT (τ = 0.1, K = 1.0)
G112	$\frac{1.0e^{-0.2S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT (τ = 0.2, K = 1.0)
G113	$\frac{1.0e^{-0.3S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT (τ = 0.3, K = 1.0)
G180	$\frac{0.8}{0.25S^2 + 0.7S + 1.0}$	N1LAT (τ = 0, K = 0.8)
G185	$\frac{0.8e^{-0.05S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT (τ = 0.05, K = 0.8)
G188	$\frac{0.8e^{-0.08S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT (τ = 0.08, K = 0.8)
G181	$\frac{0.8e^{-0.1S}}{0.25S^2 + 0.7S + 1.0}$	N1LAT (τ = 0.1, K = 0.8)

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Figure A-3. (Concluded) List of Configuration Transfer Functions

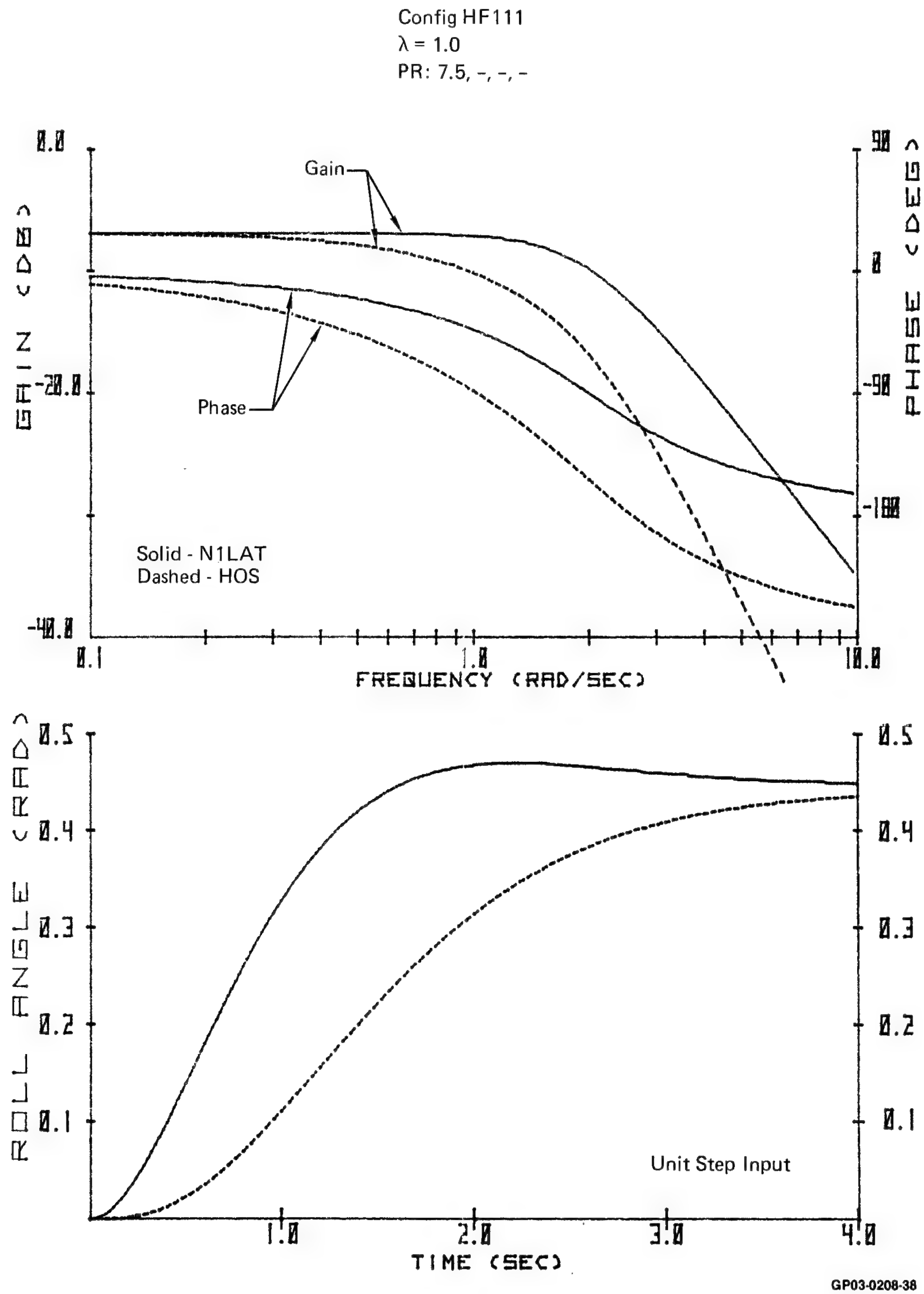

Figure A-4. Frequency and Time Response

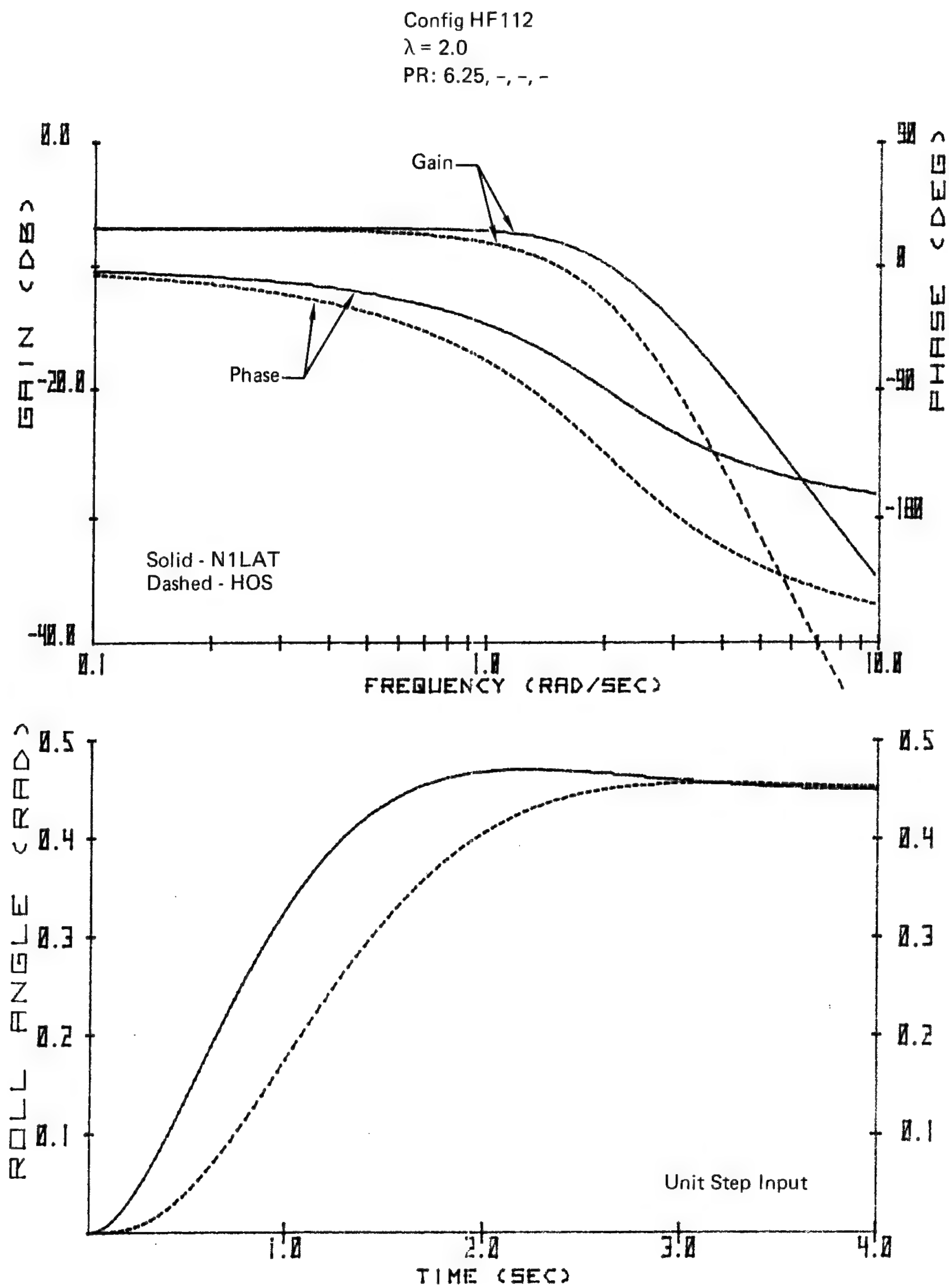

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Figure A-5. Frequency and Time Response

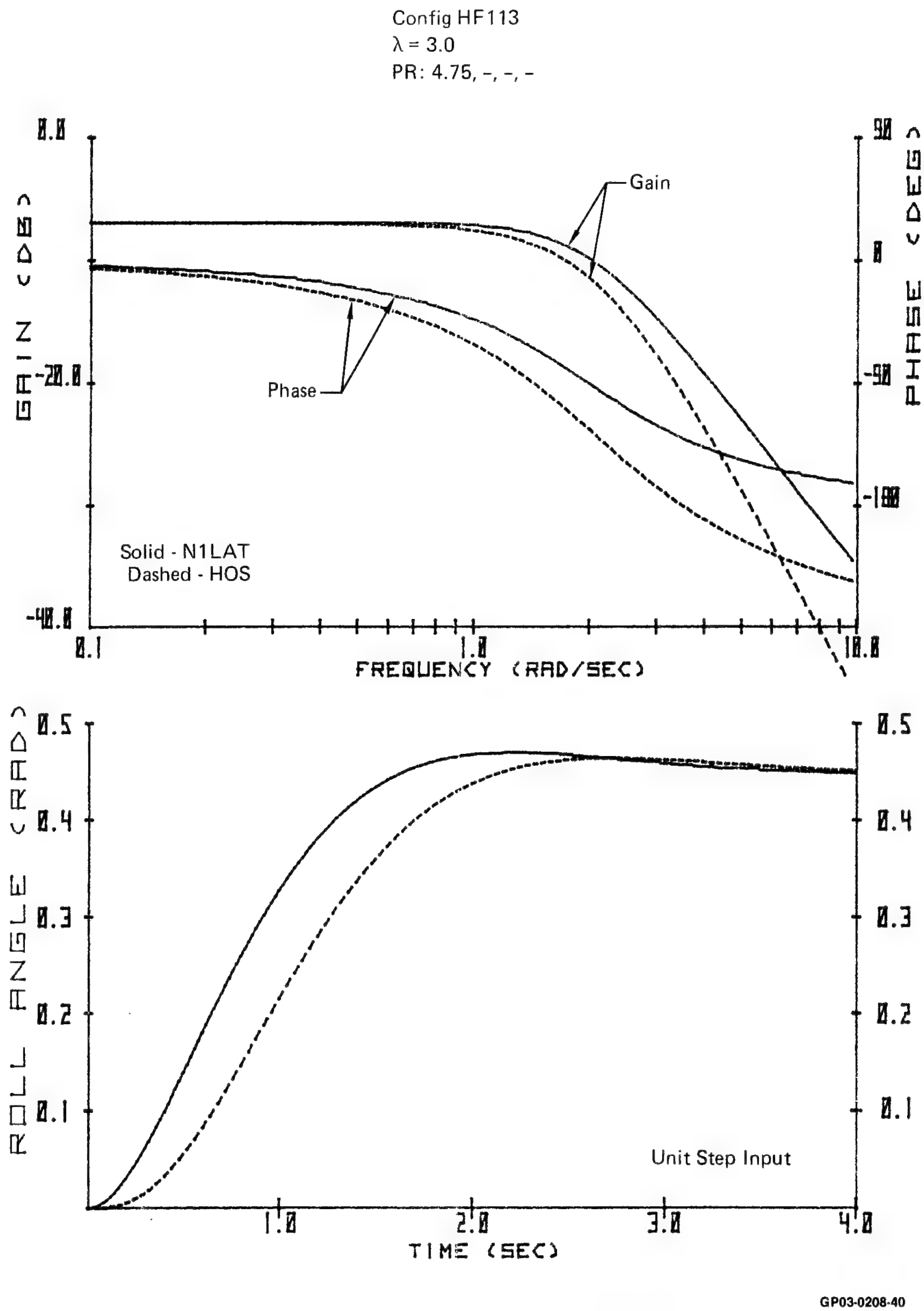

Figure A-6. Frequency and Time Response

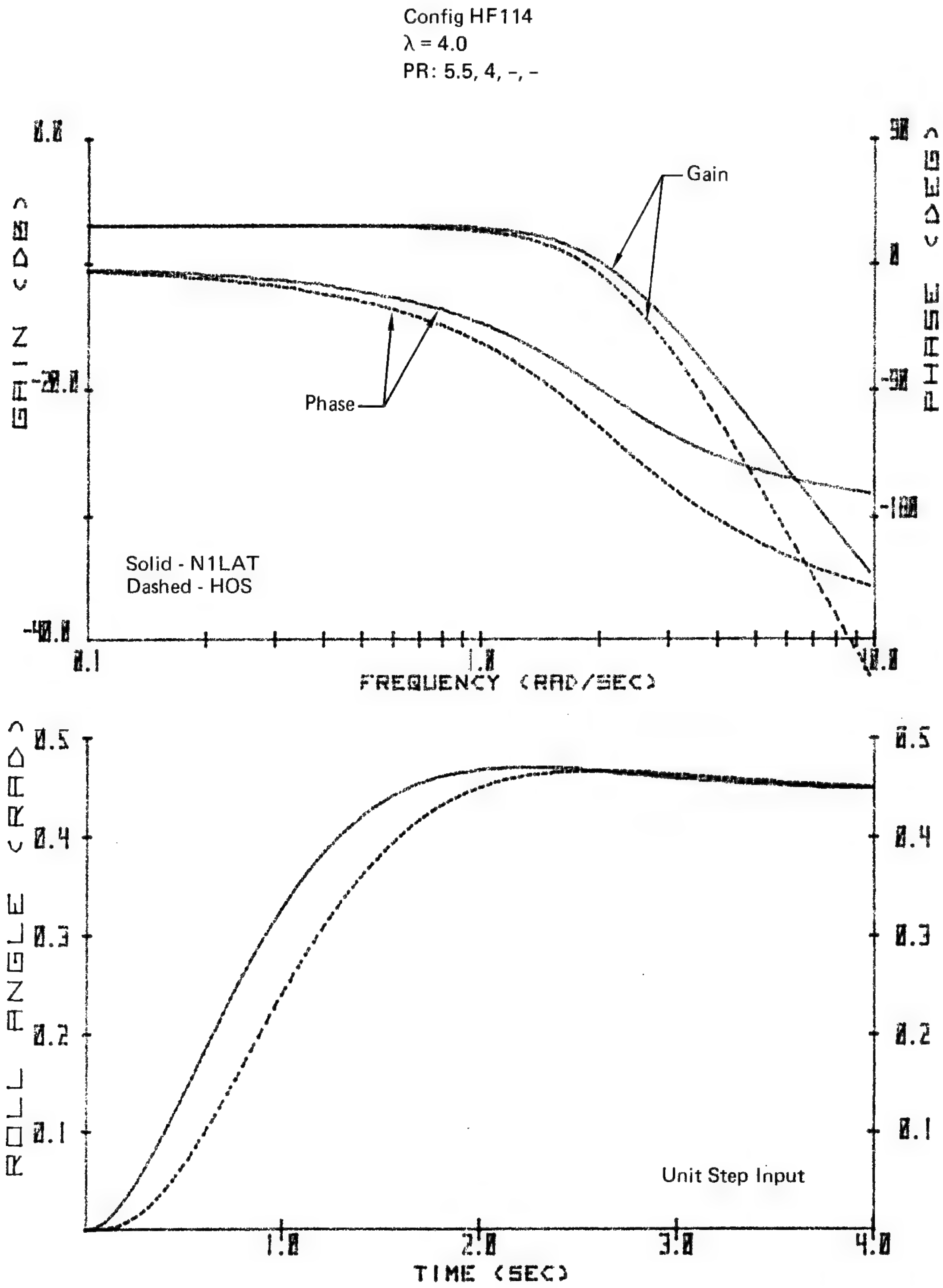

Figure A-7. Frequency and Time Response

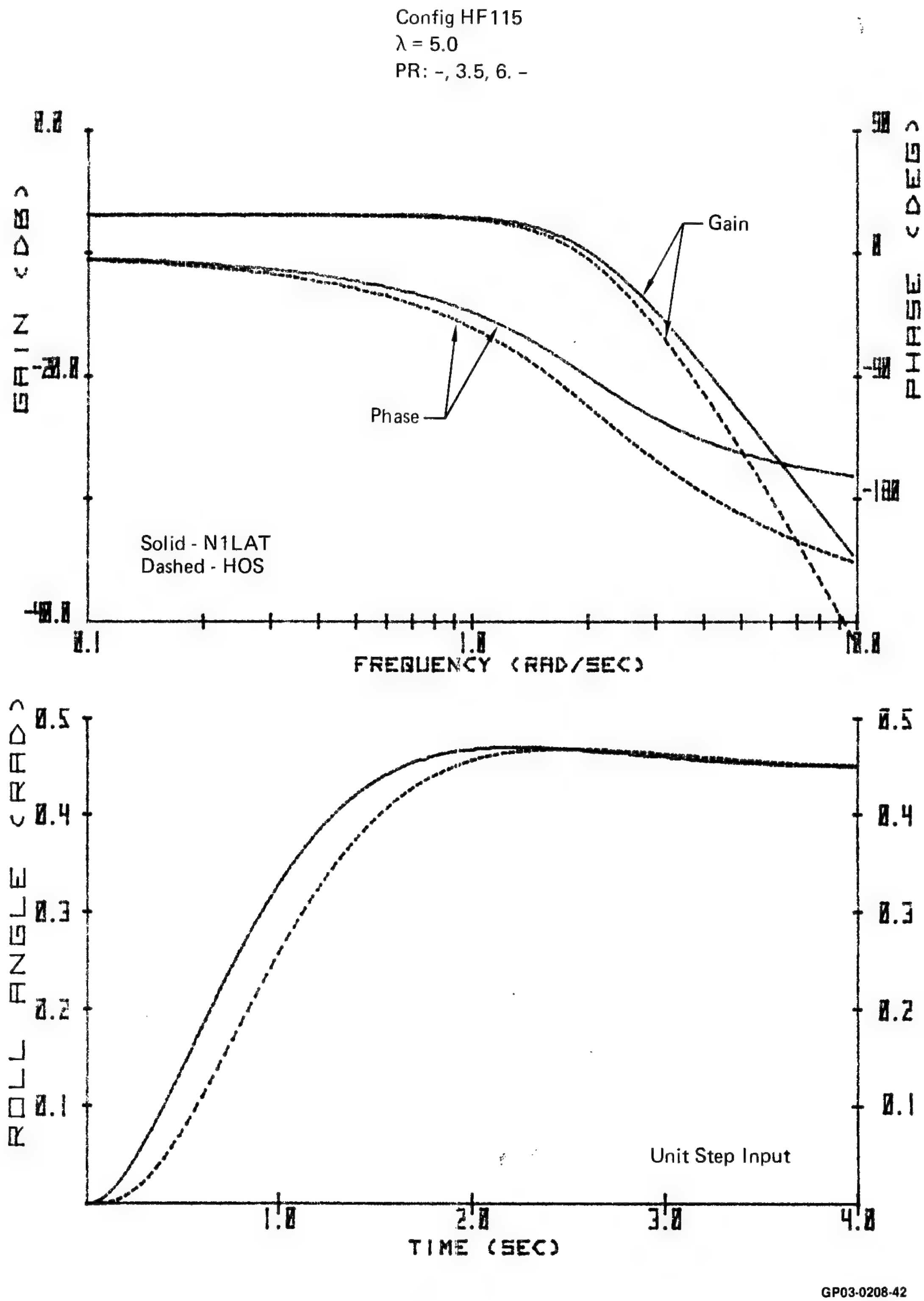

Figure A-8. Frequency and Time Response

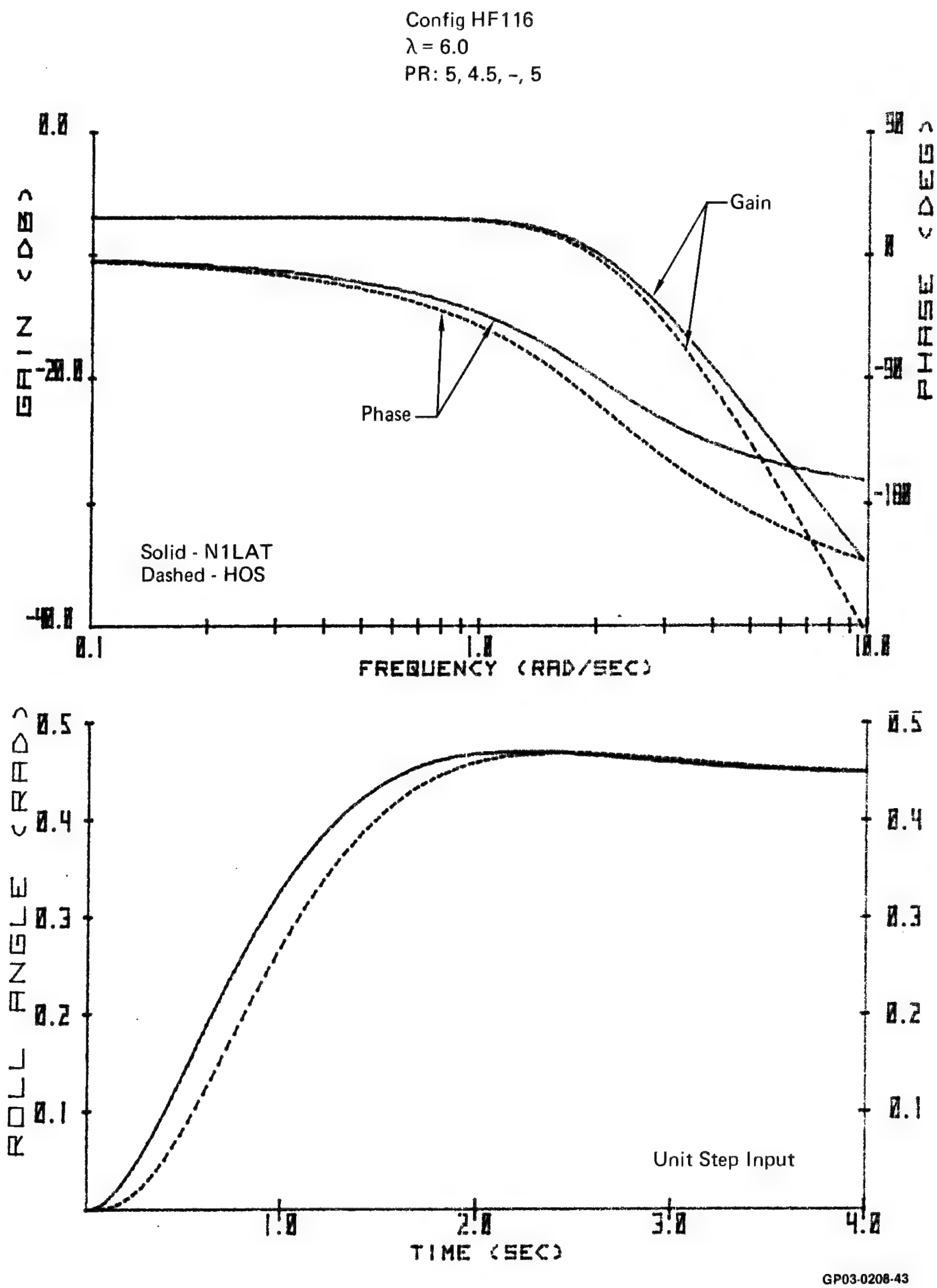

Figure A-9. Frequency and Time Response

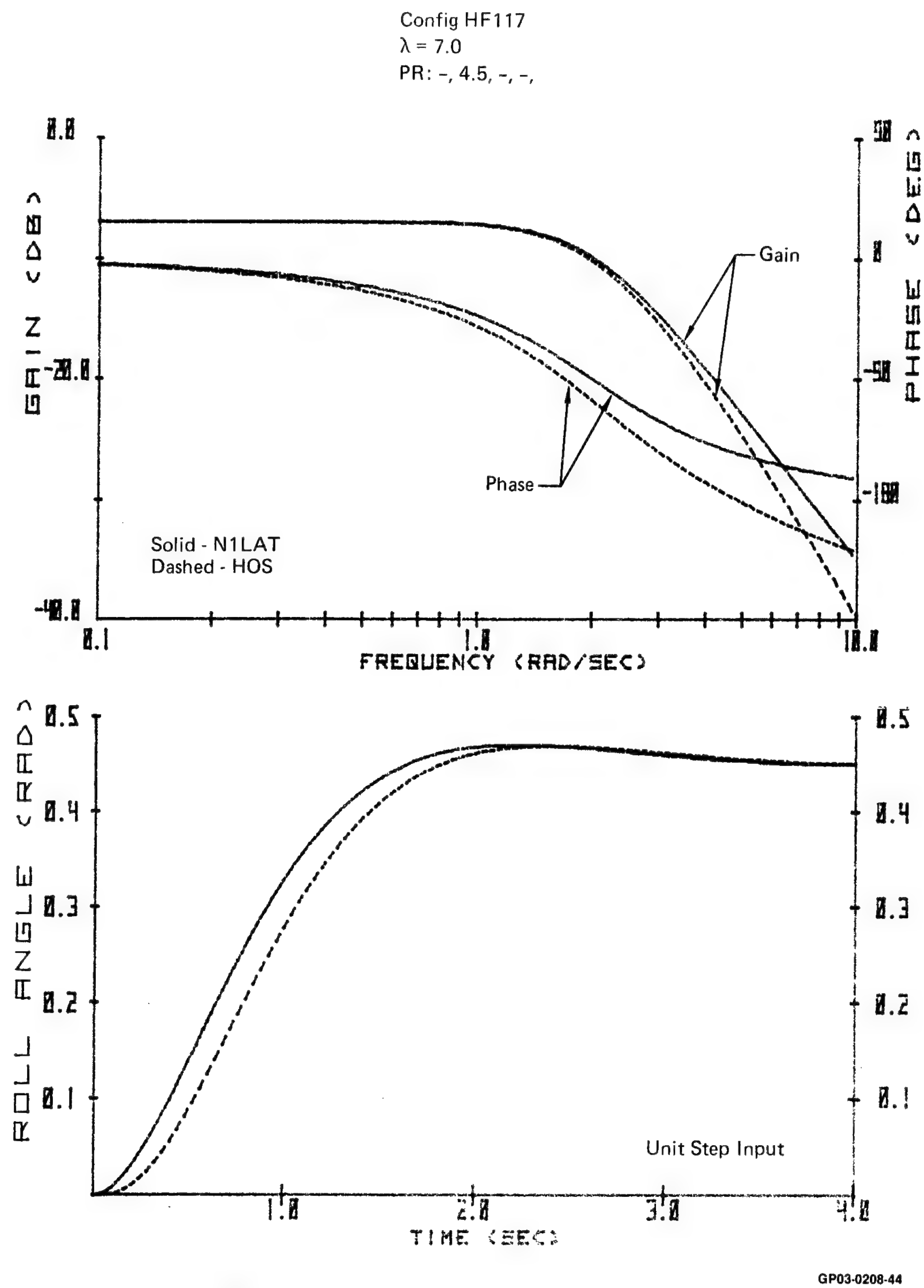

Figure A-10. Frequency and Time Response

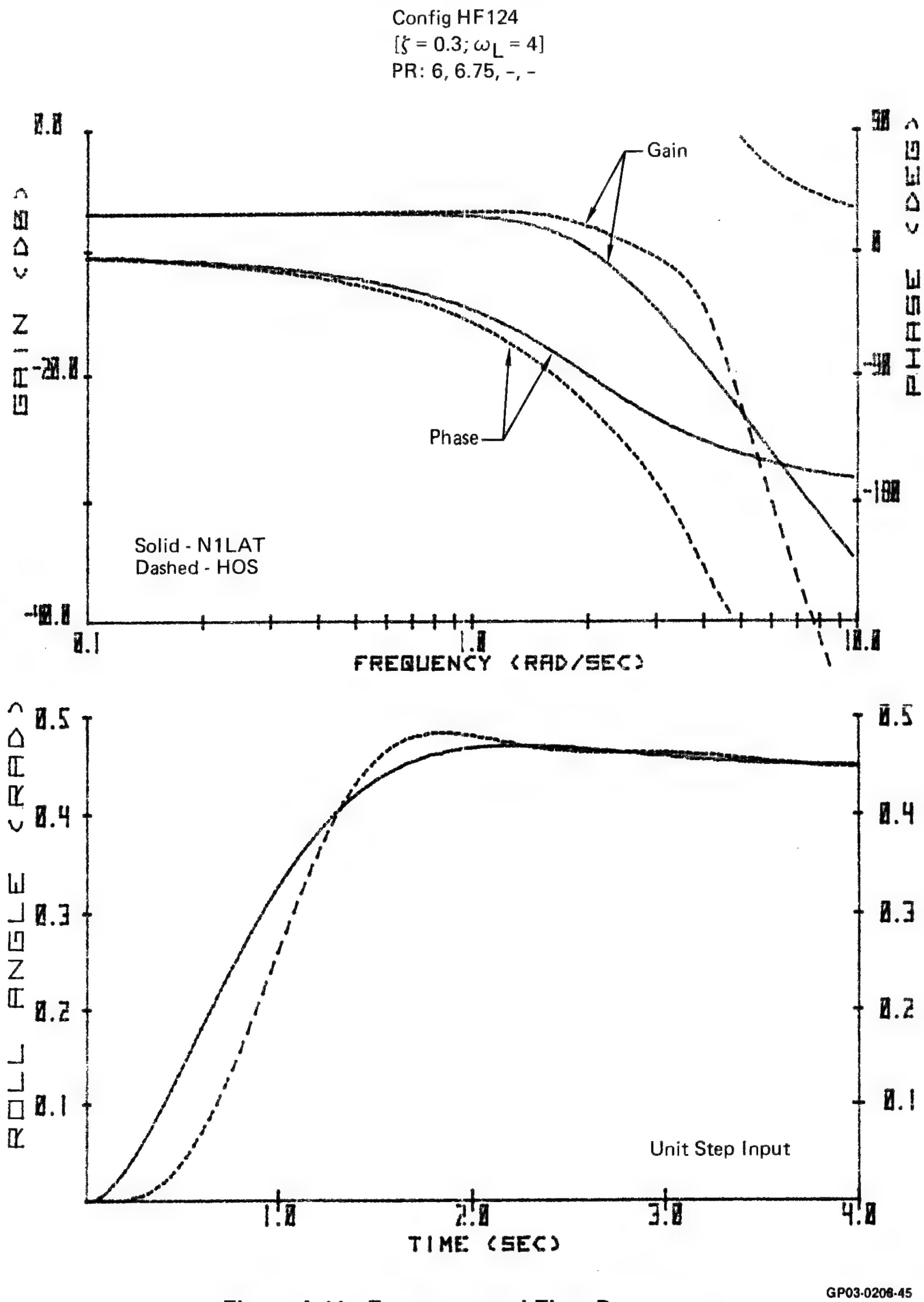

Figure A-11. Frequency and Time Response

Config HF125
[$\zeta = 0.3; \omega_L = 5$]
PR: 5.5, 6, –, 7.5

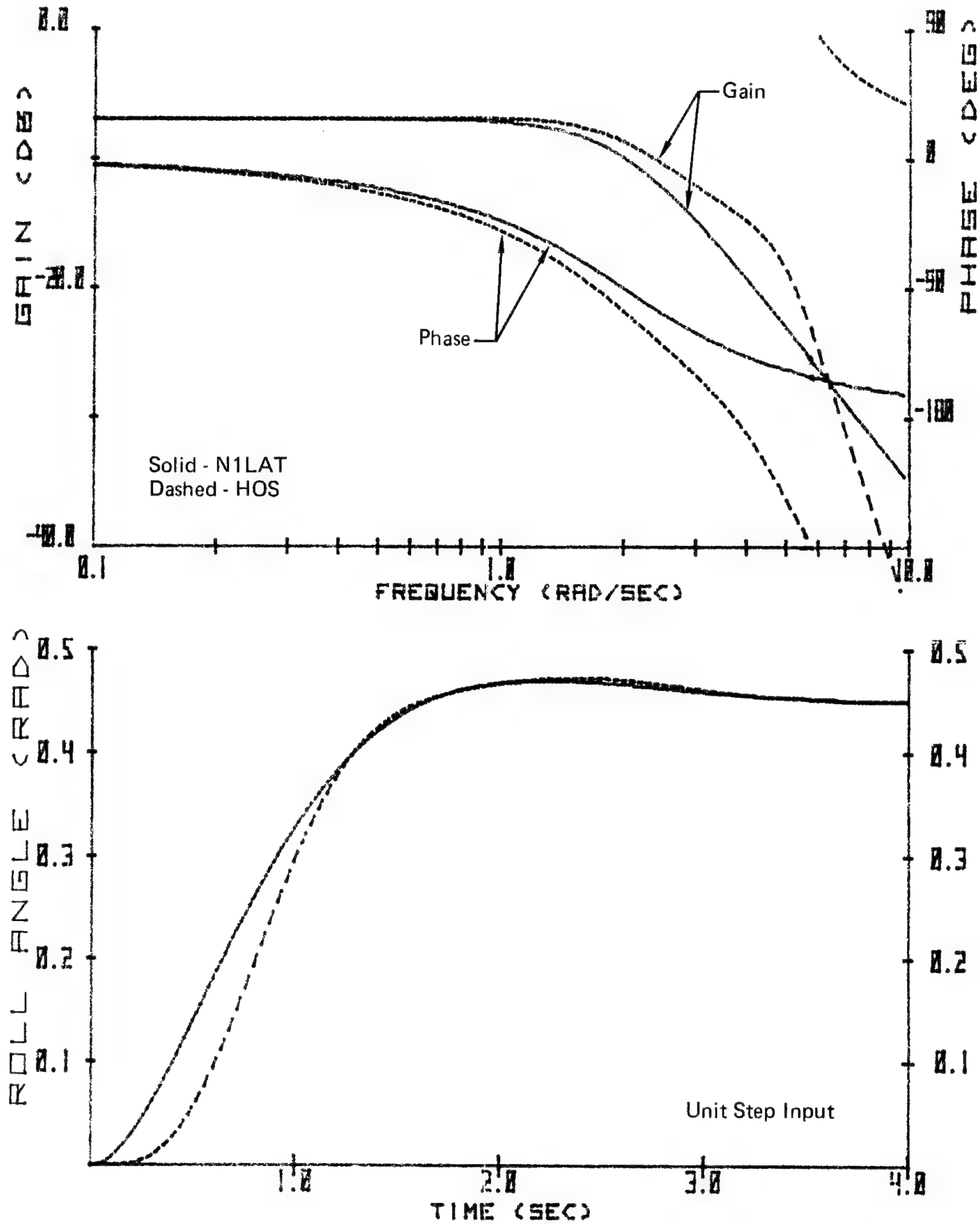

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Figure A-12. Frequency and Time Response

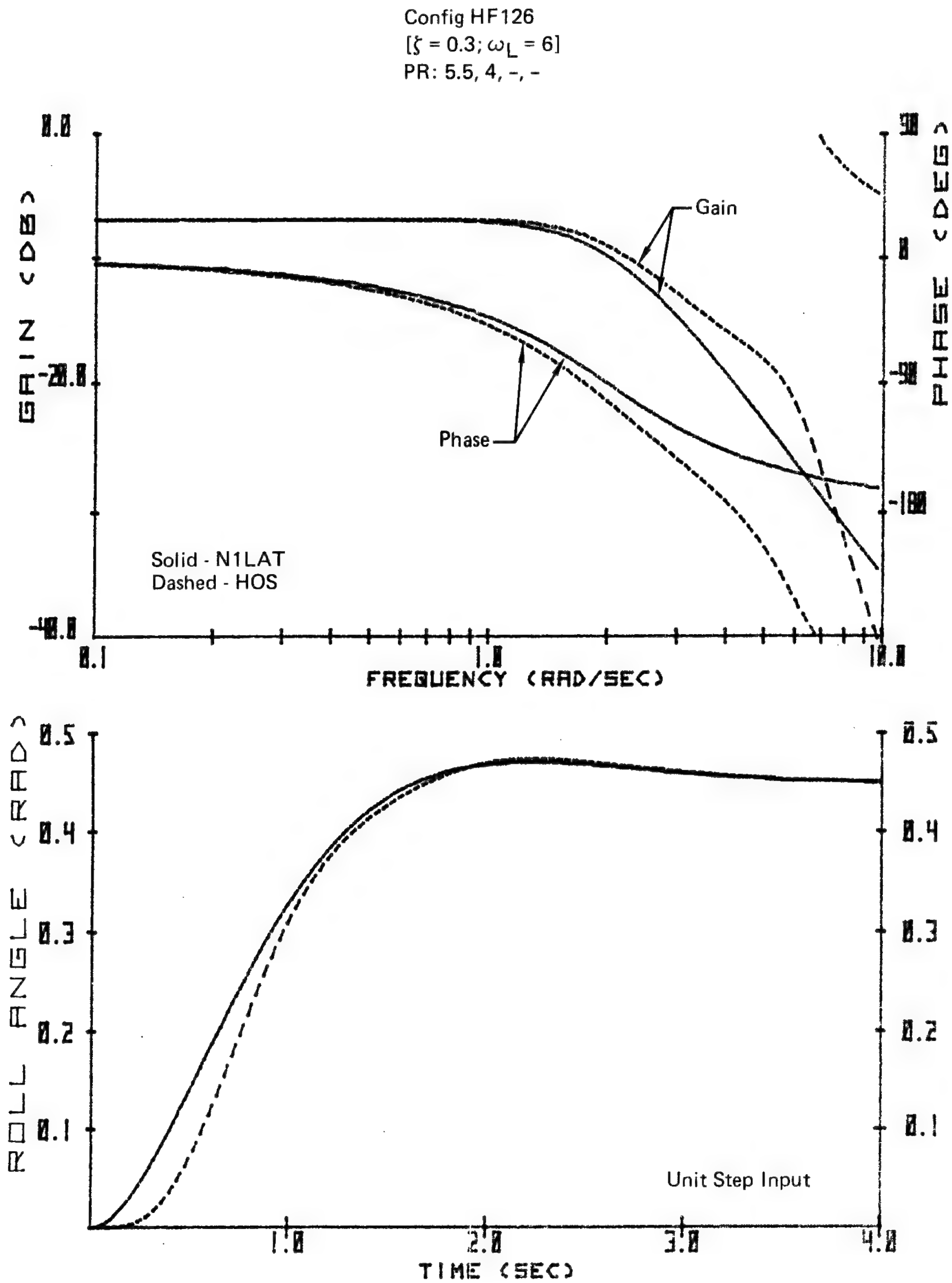

Figure A-13. Frequency and Time Response

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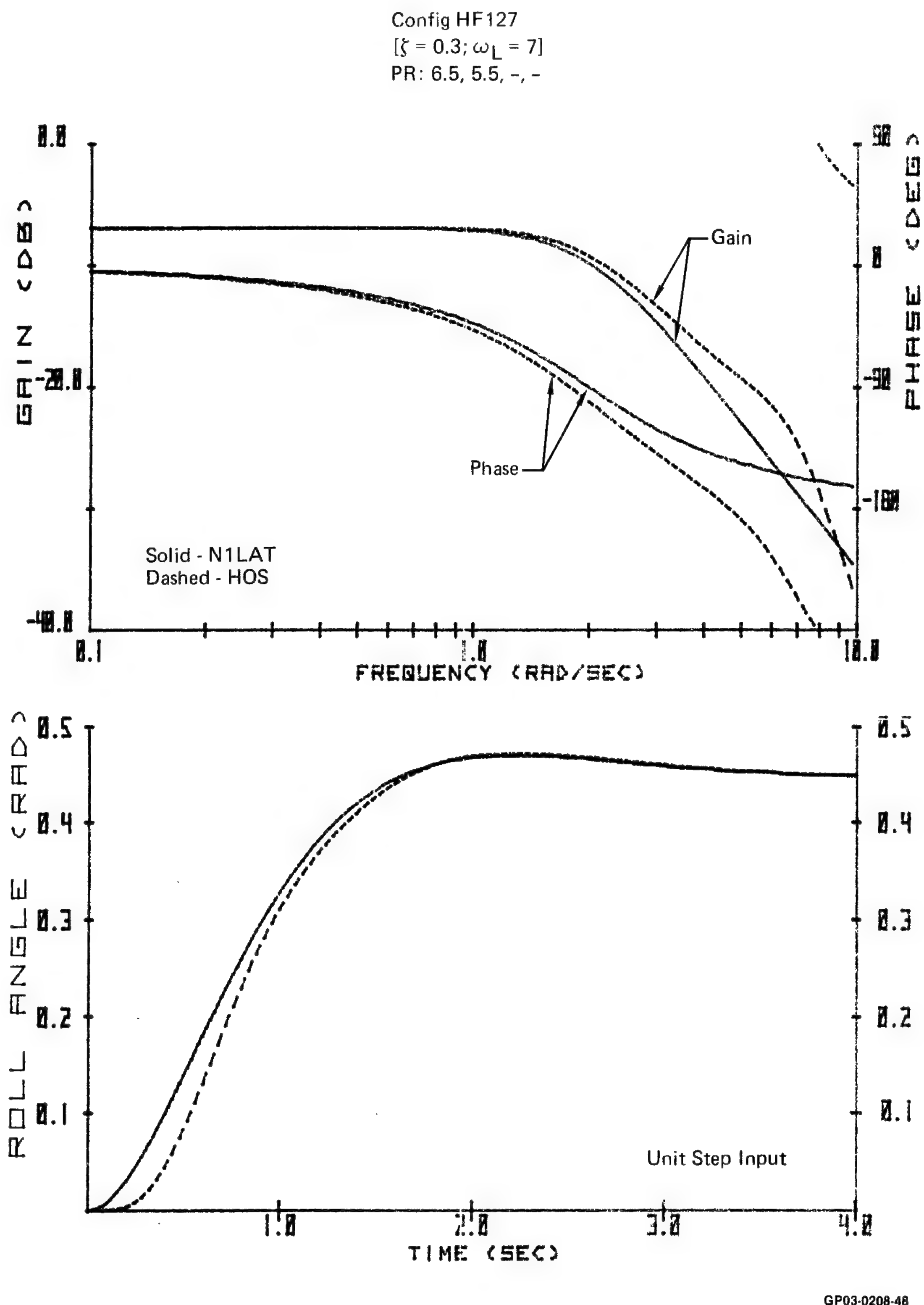

Figure A-14. Frequency and Time Response

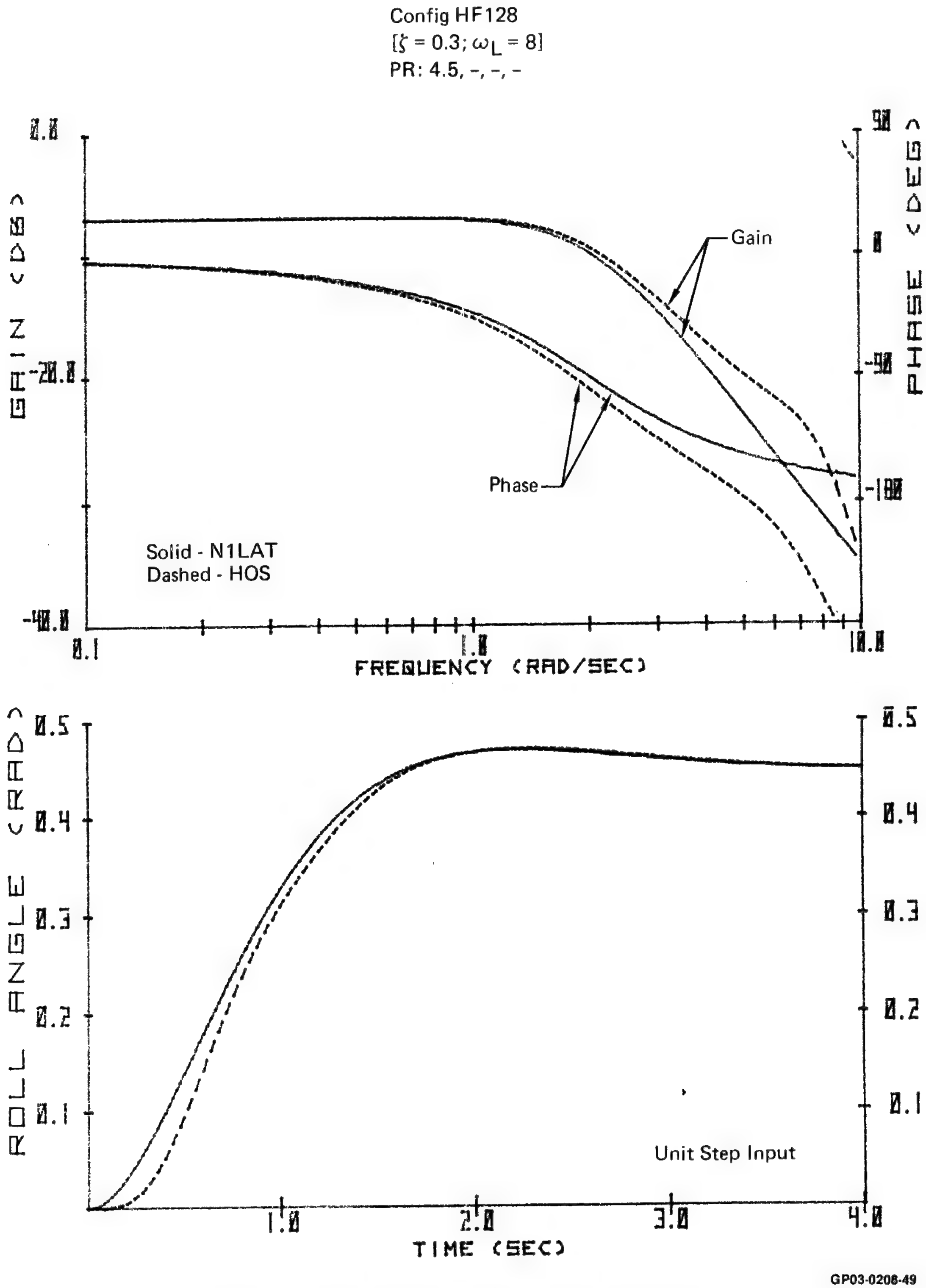

Figure A-15. Frequency and Time Response

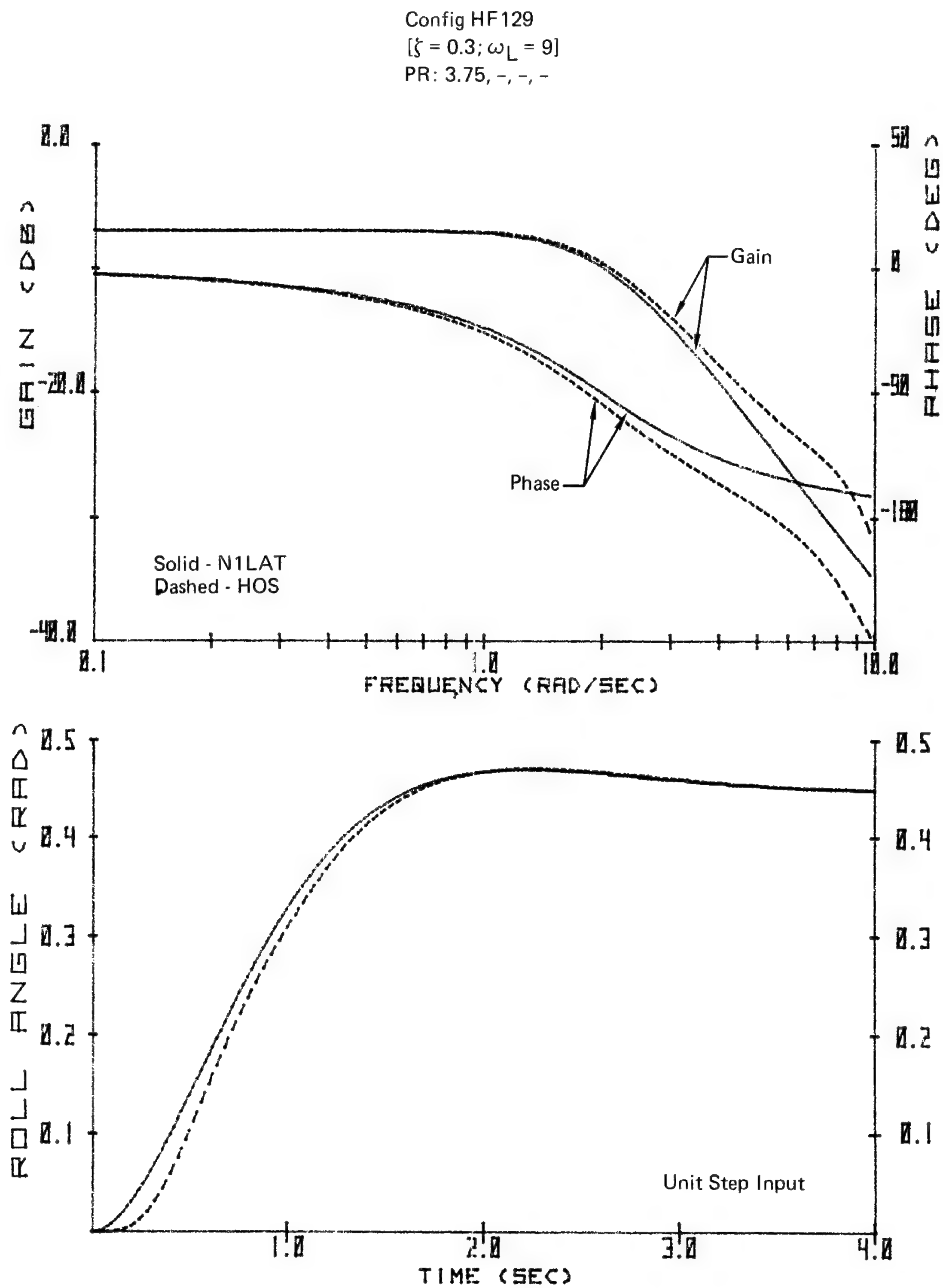

Figure A-16. Frequency and Time Response

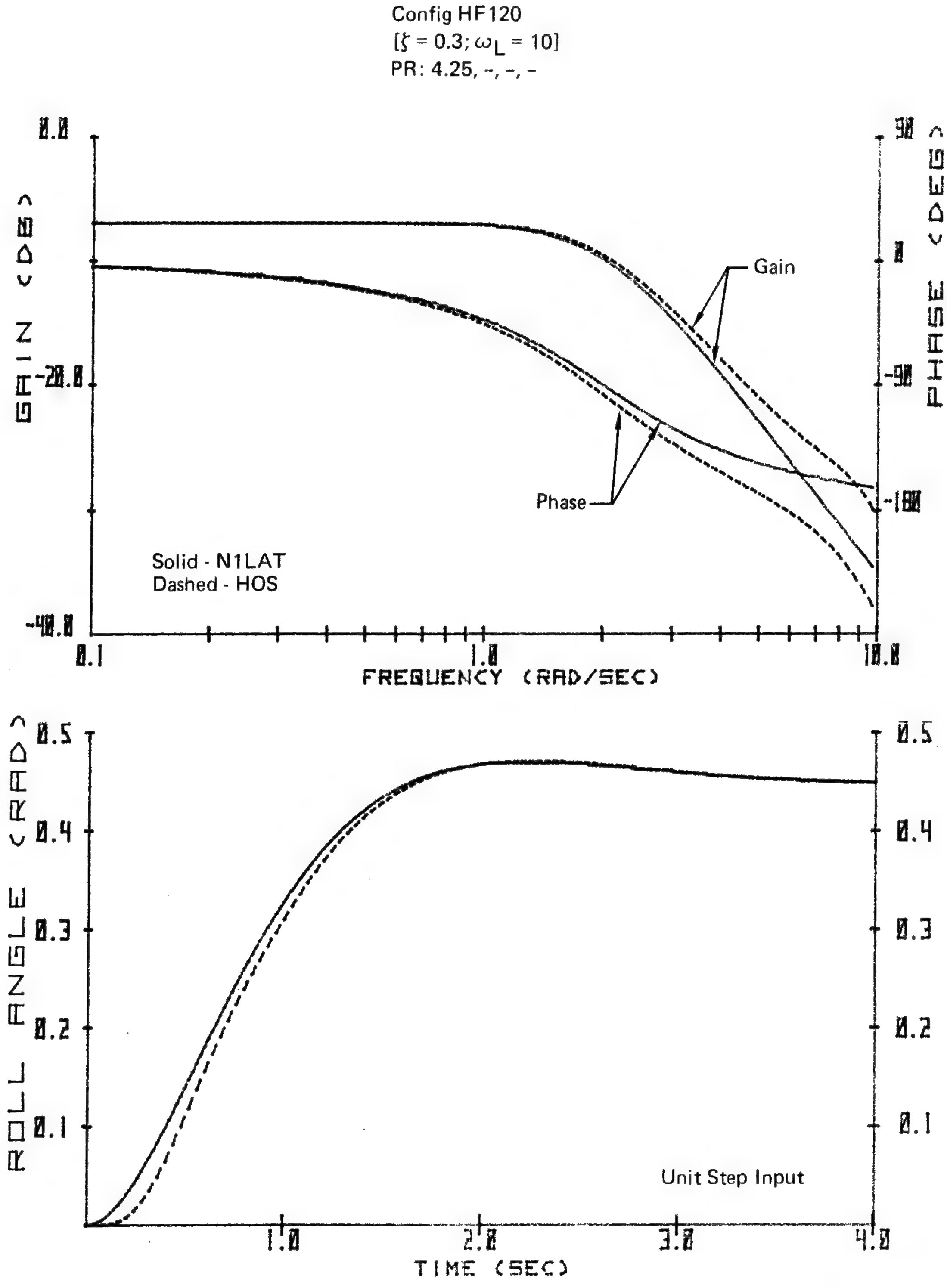

Figure A-17. Frequency and Time Response

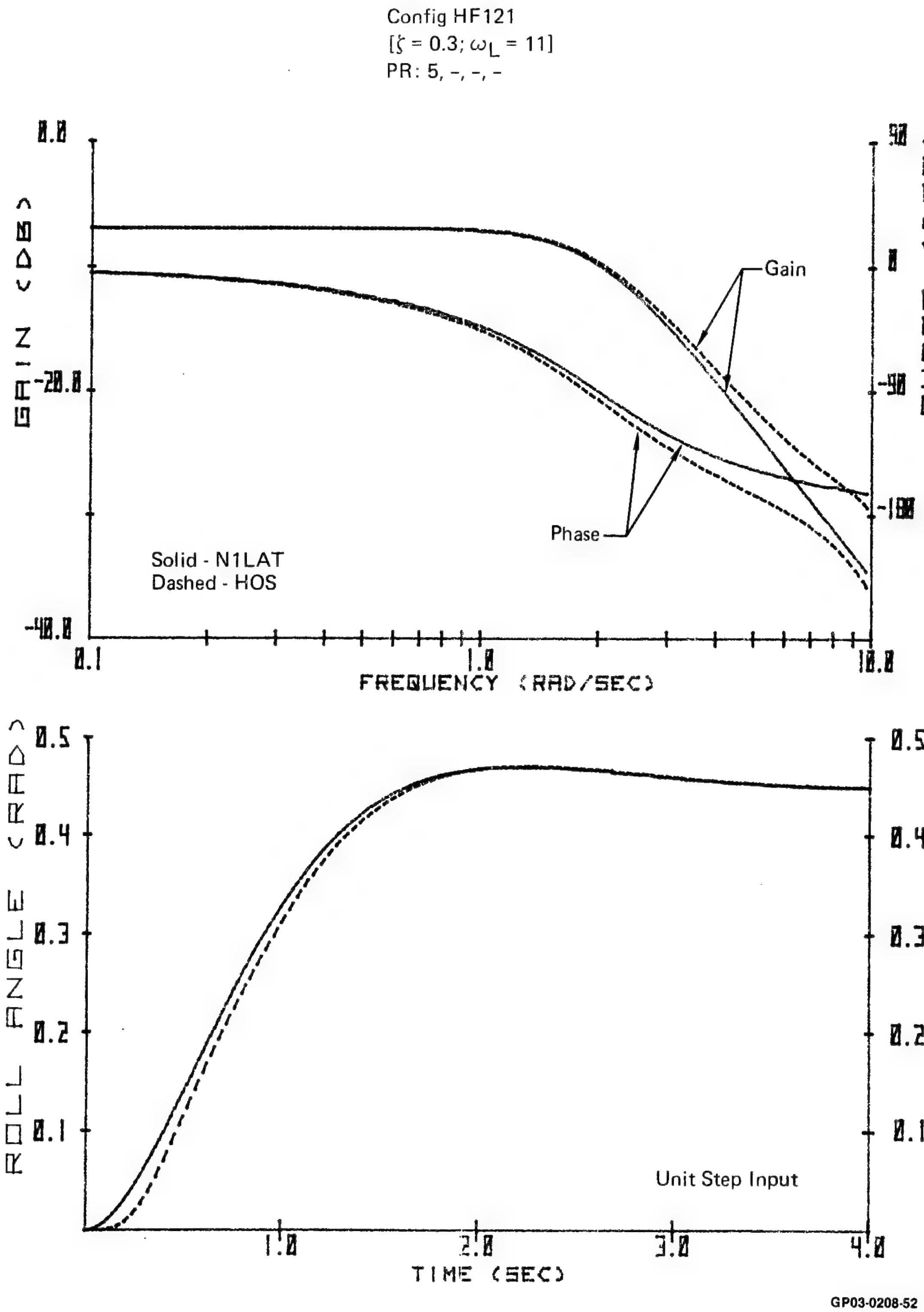

Figure A-18. Frequency and Time Response

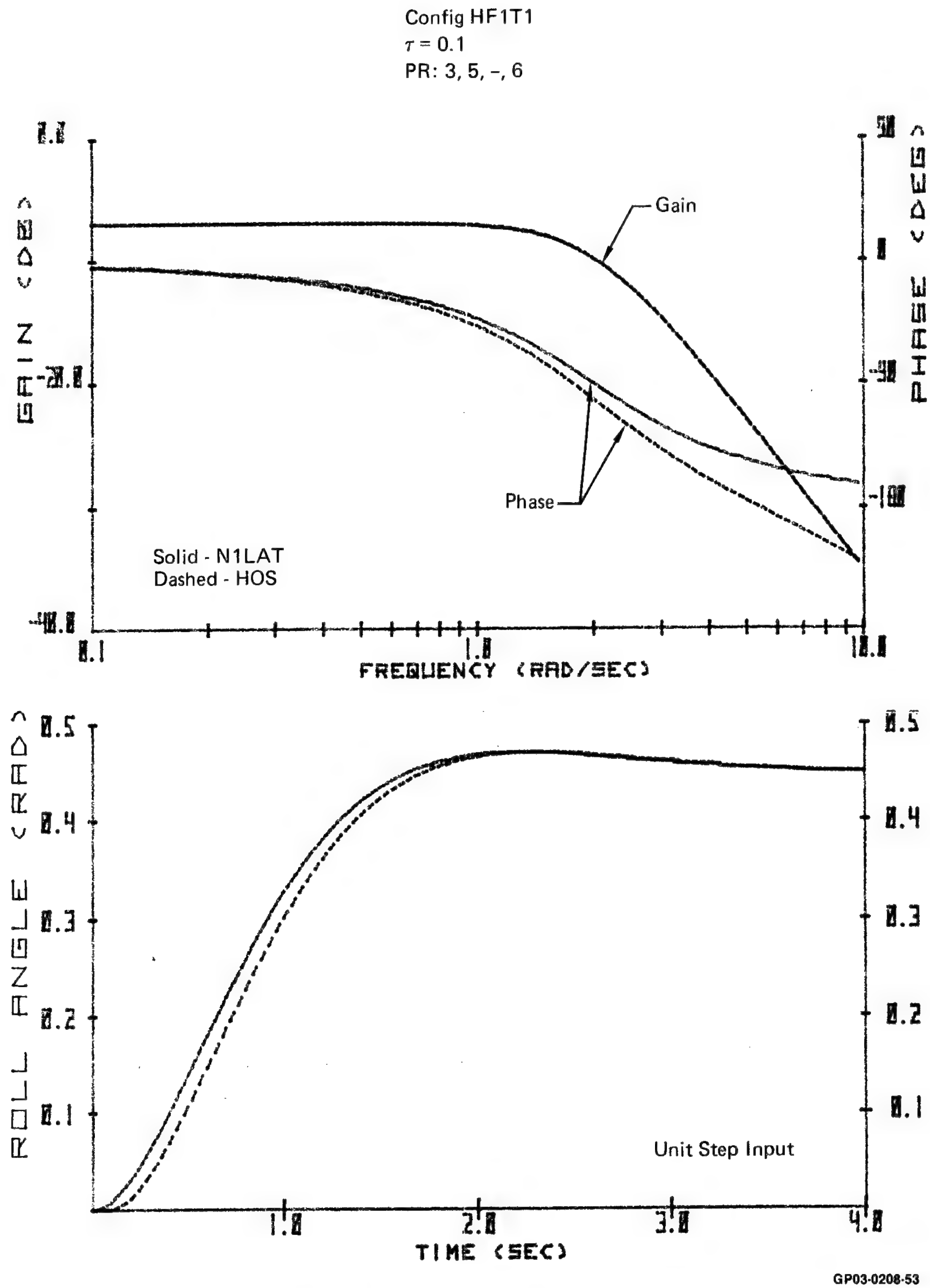

Figure A-19. Frequency and Time Response

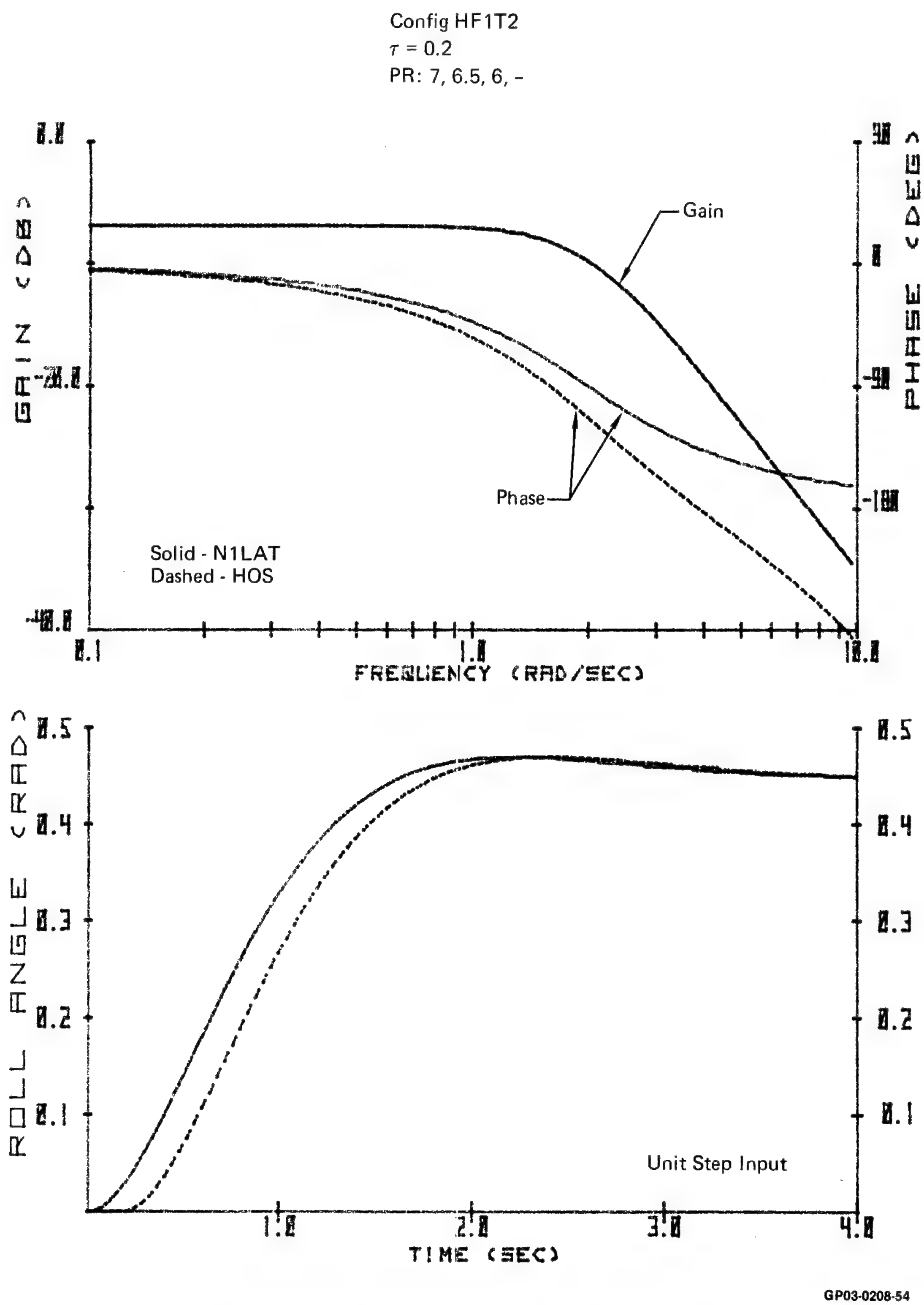

Figure A-20. Frequency and Time Response

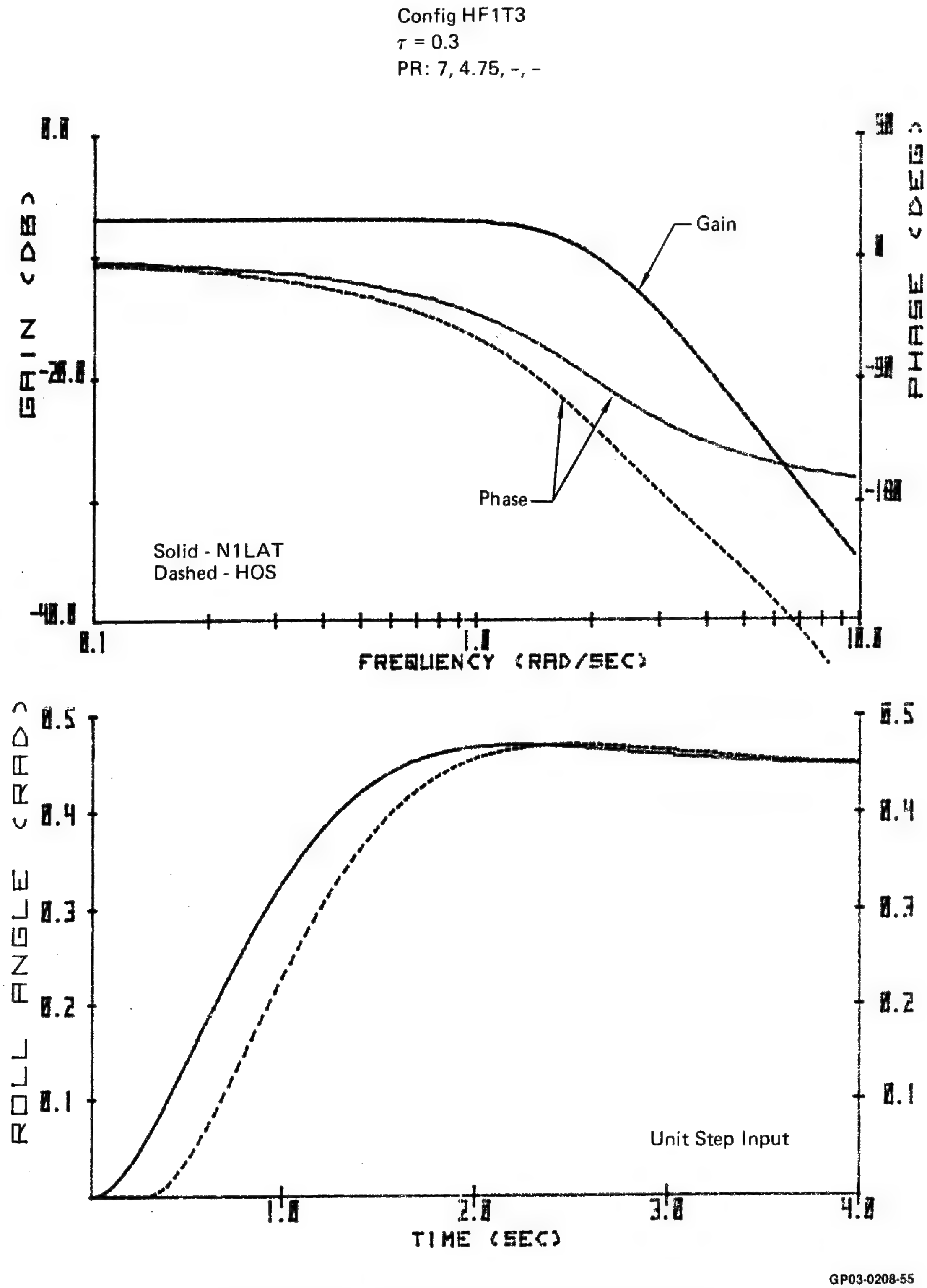

Figure A-21. Frequency and Time Response

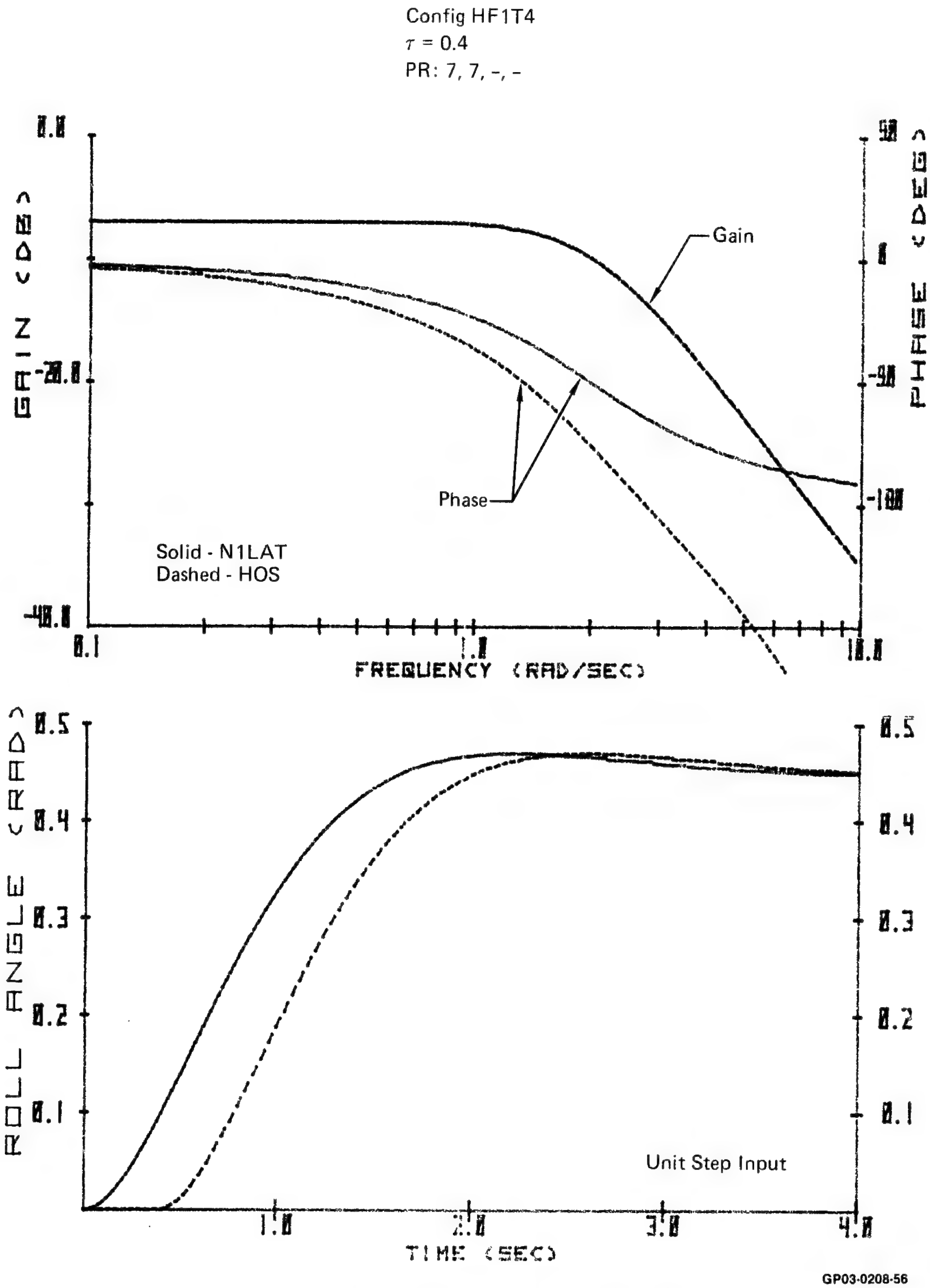

Figure A-22. Frequency and Time Response

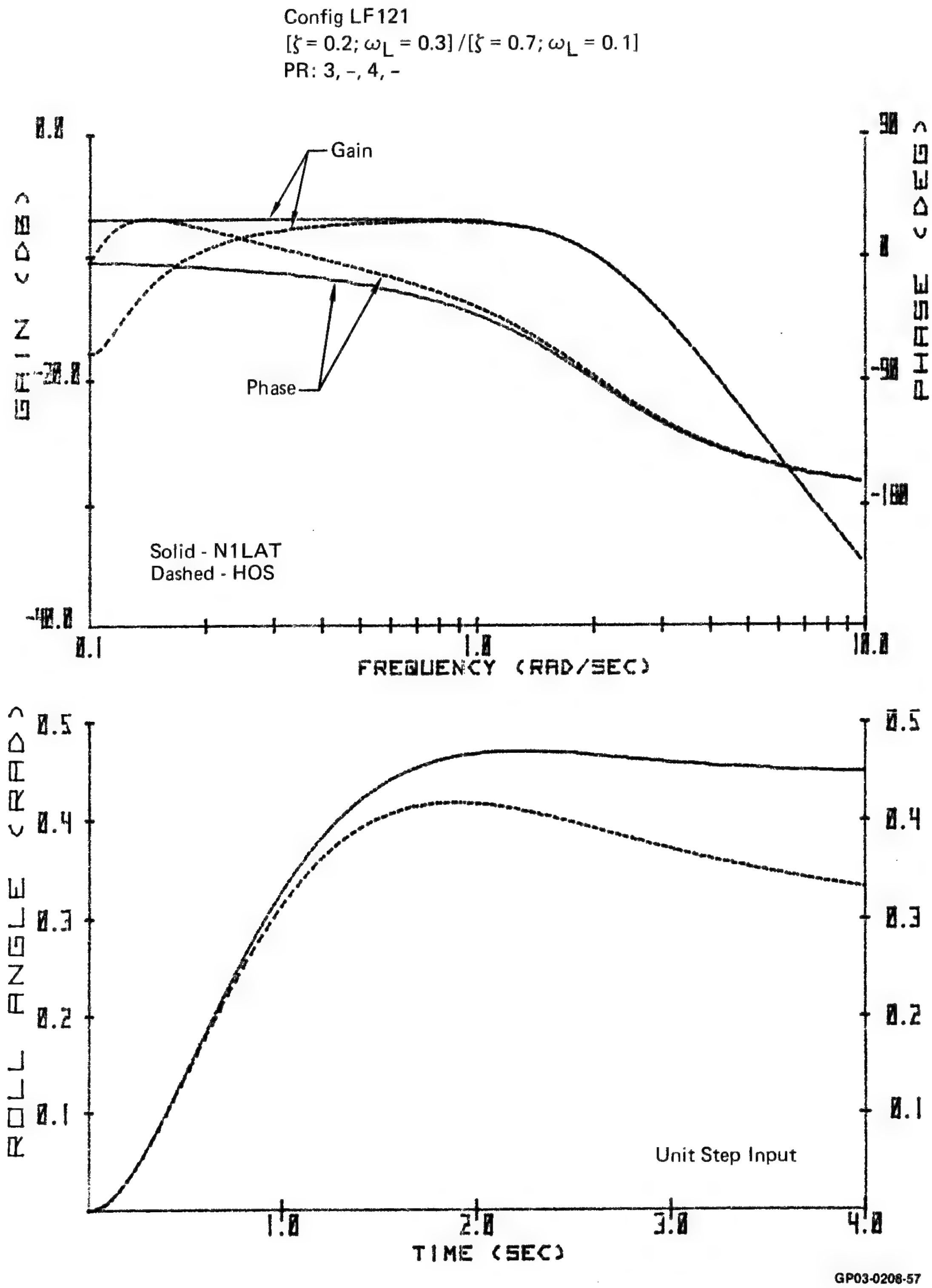

Figure A-23. Frequency and Time Response

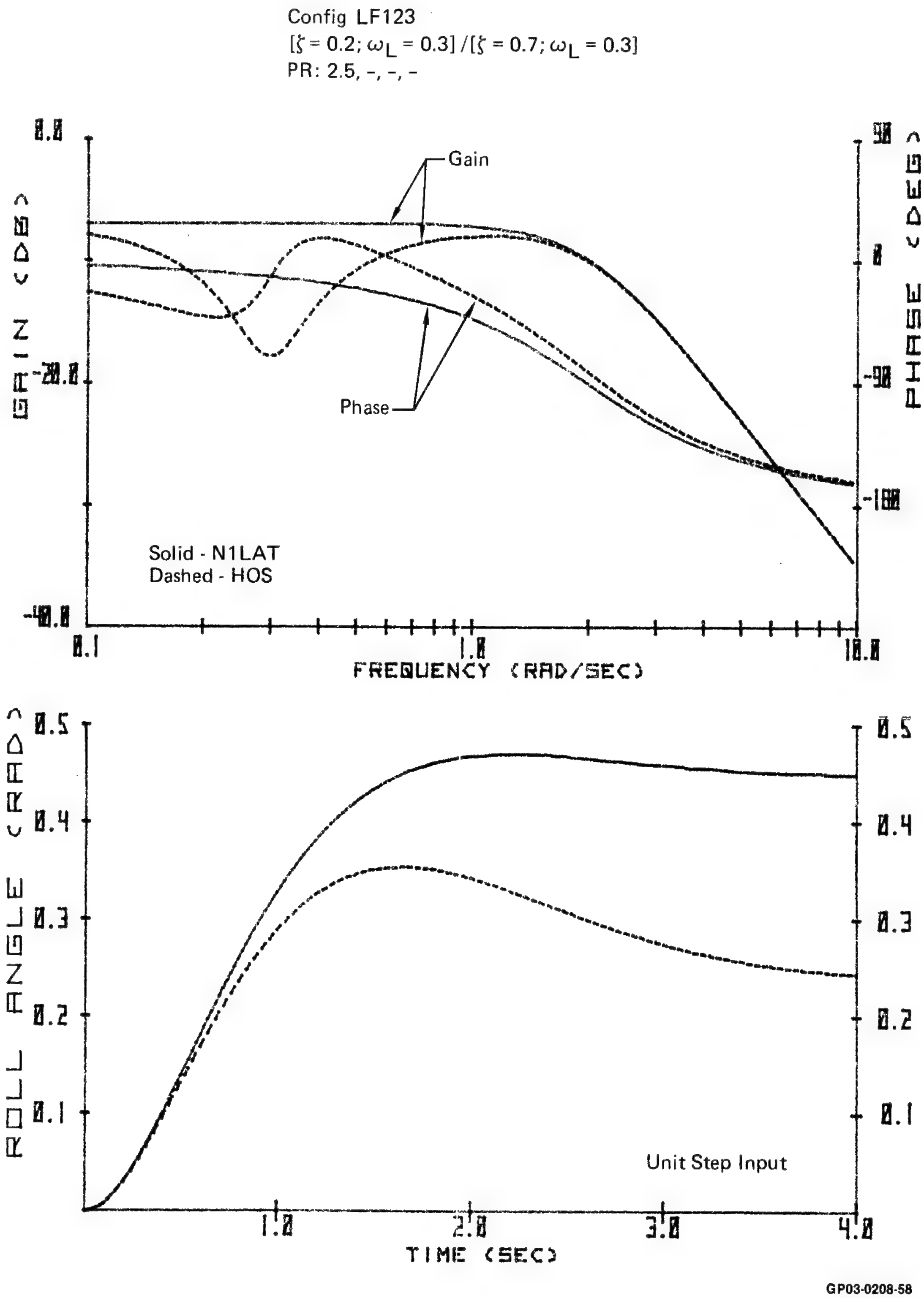

Figure A-24. Frequency and Time Response

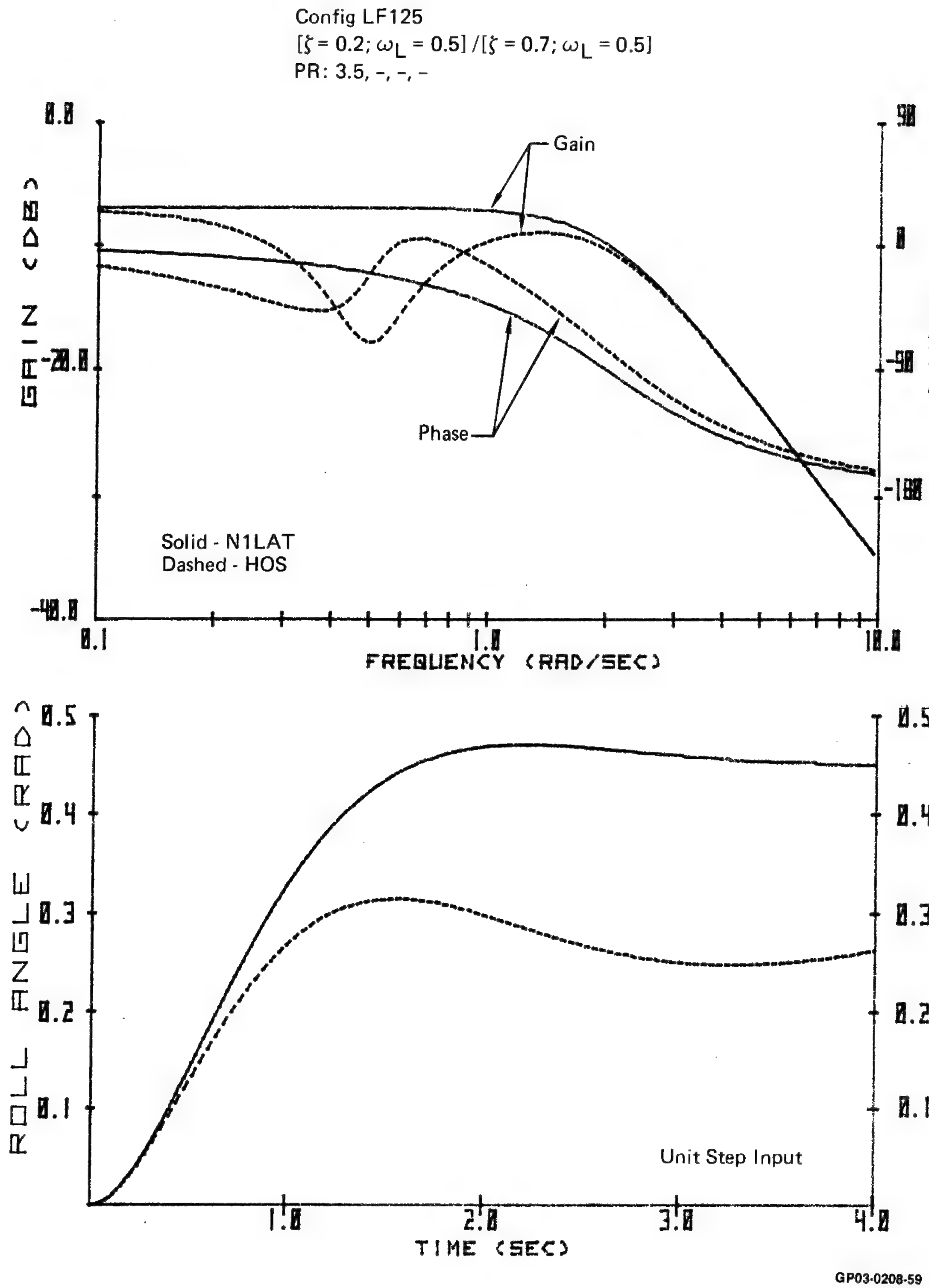

Figure A-25. Frequency and Time Response

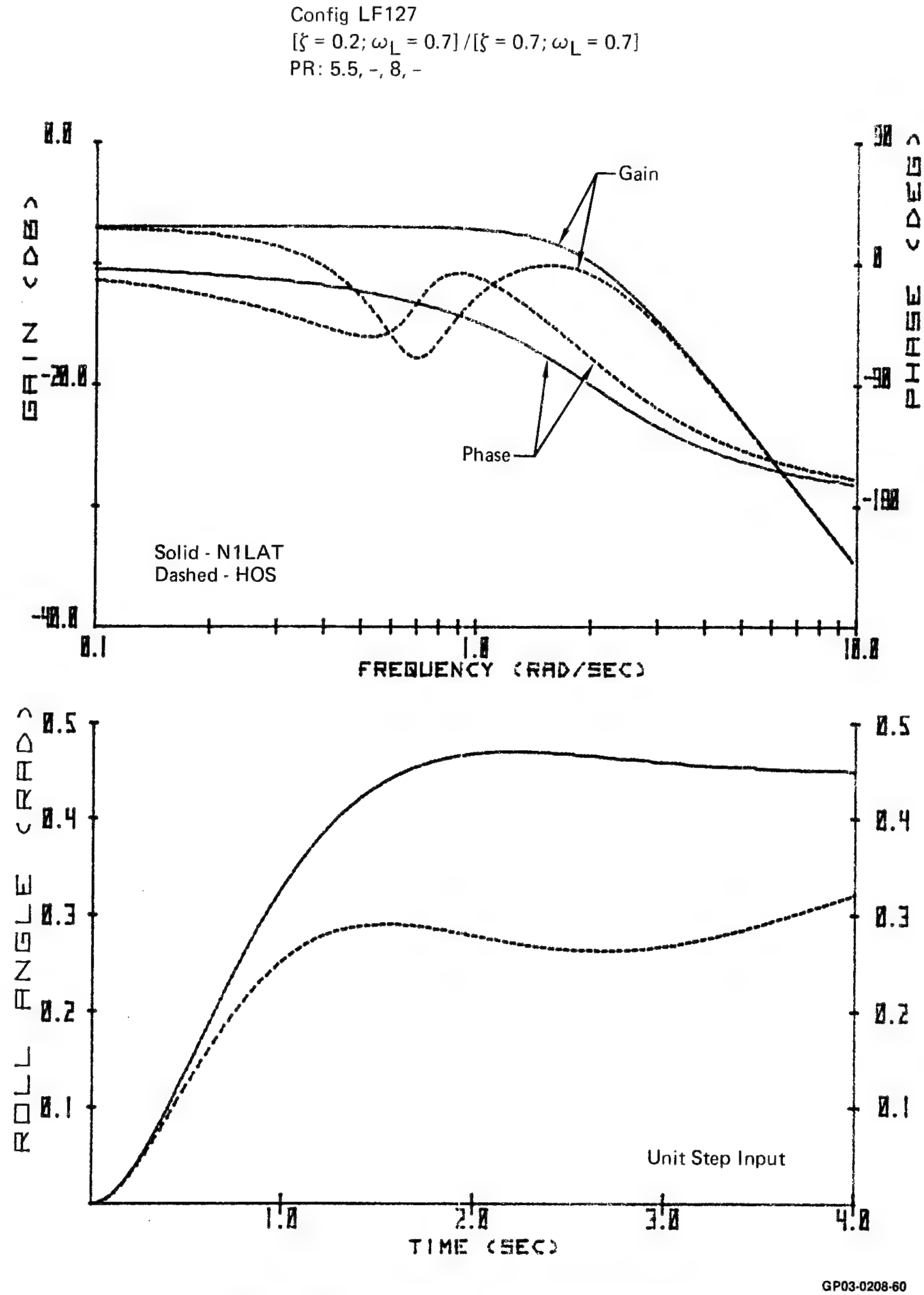

Figure A-26. Frequency and Time Response

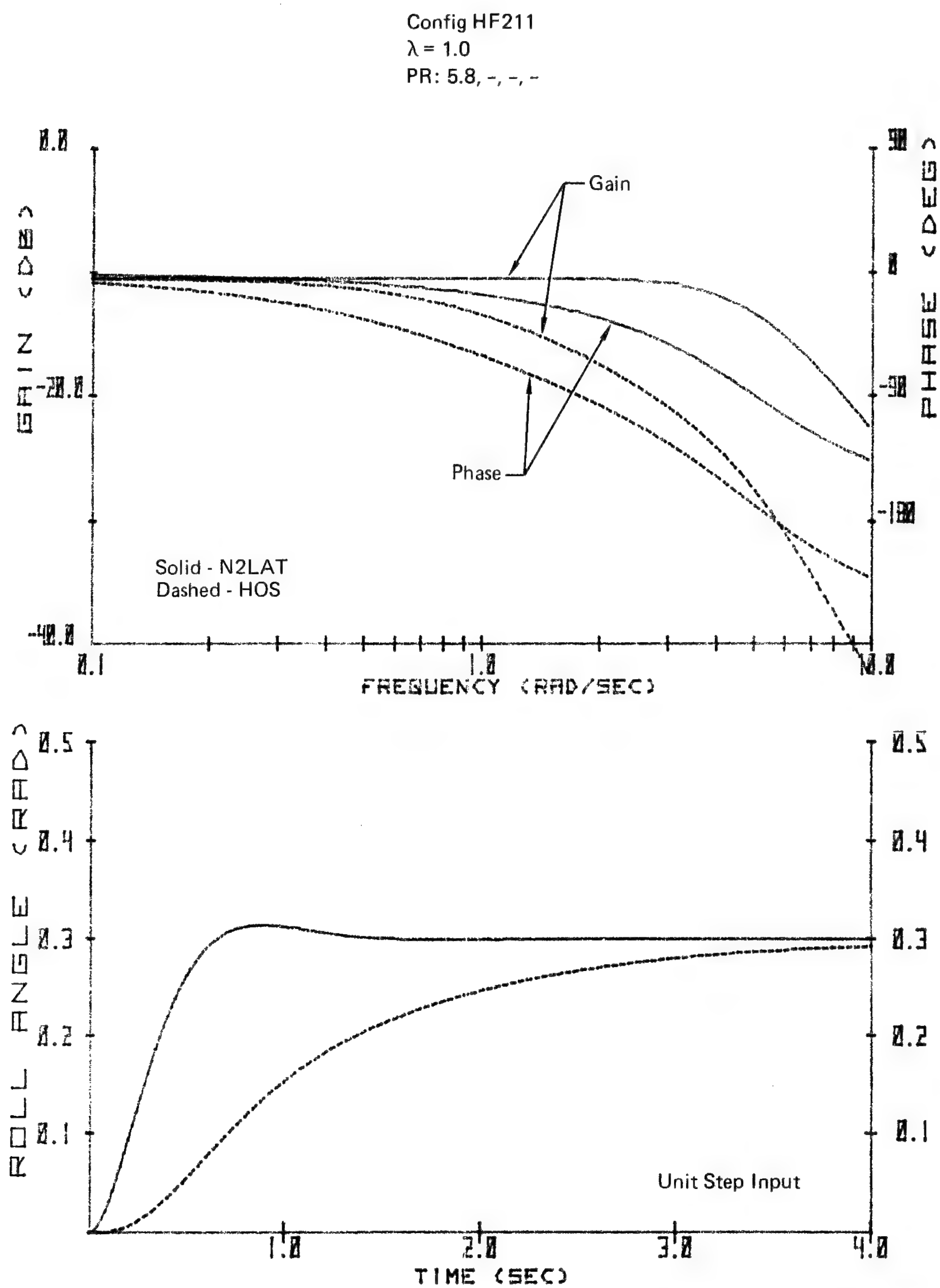

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Figure A-27. Frequency and Time Response

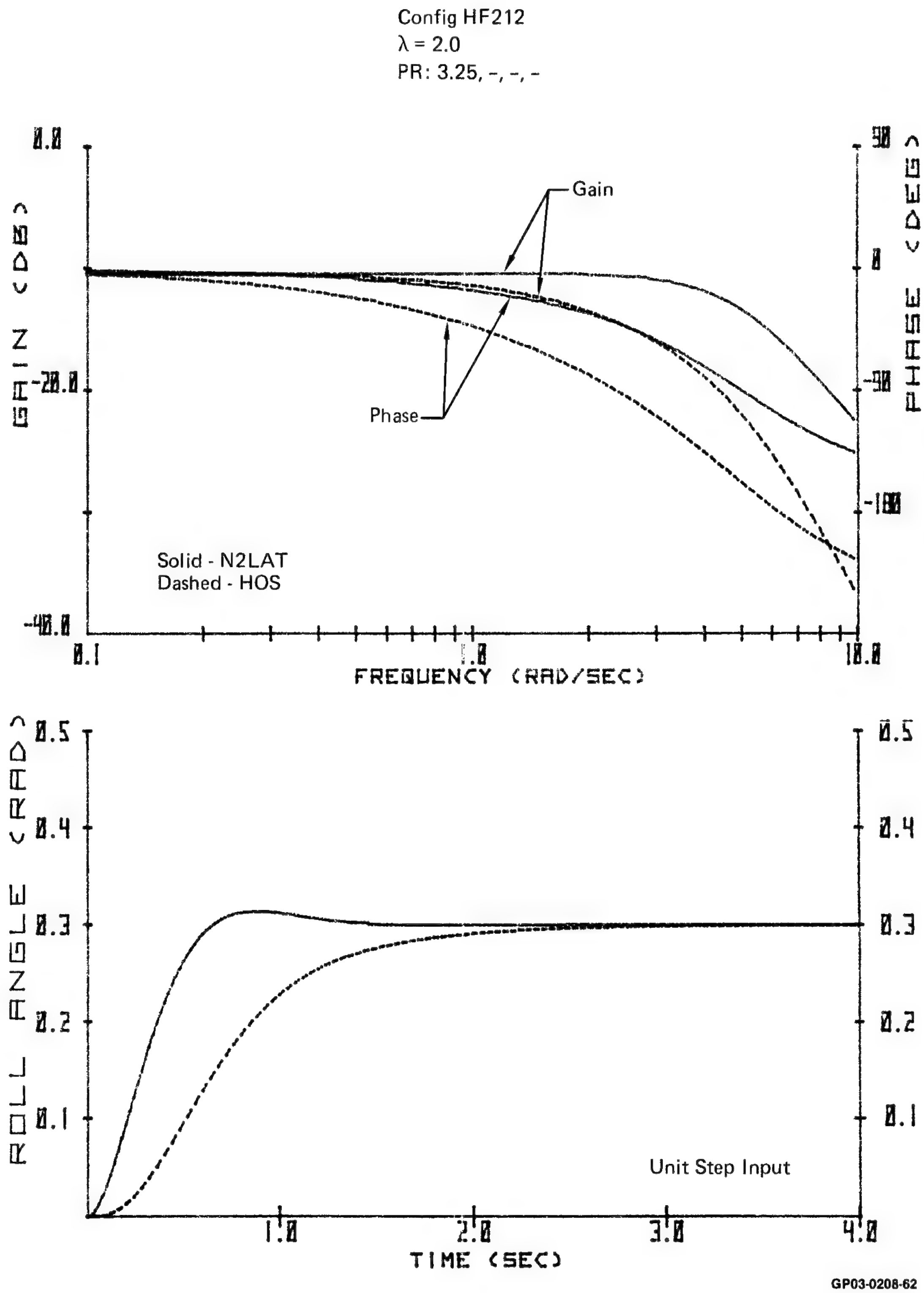


Figure A-28. Frequency and Time Response

Config HF213
λ = 3.0
PR: 3.25, -, -, -

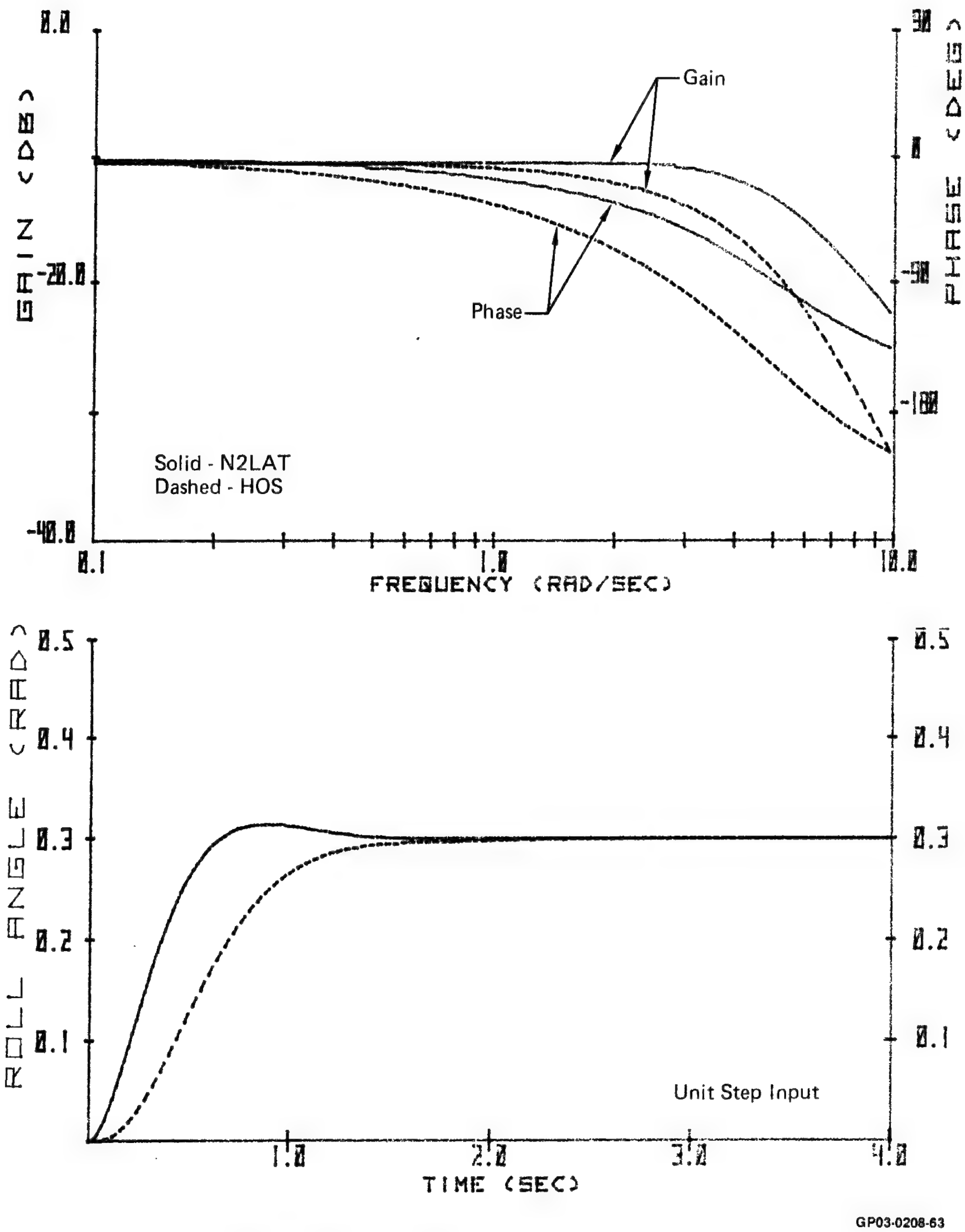


Figure A-29. Frequency and Time Response

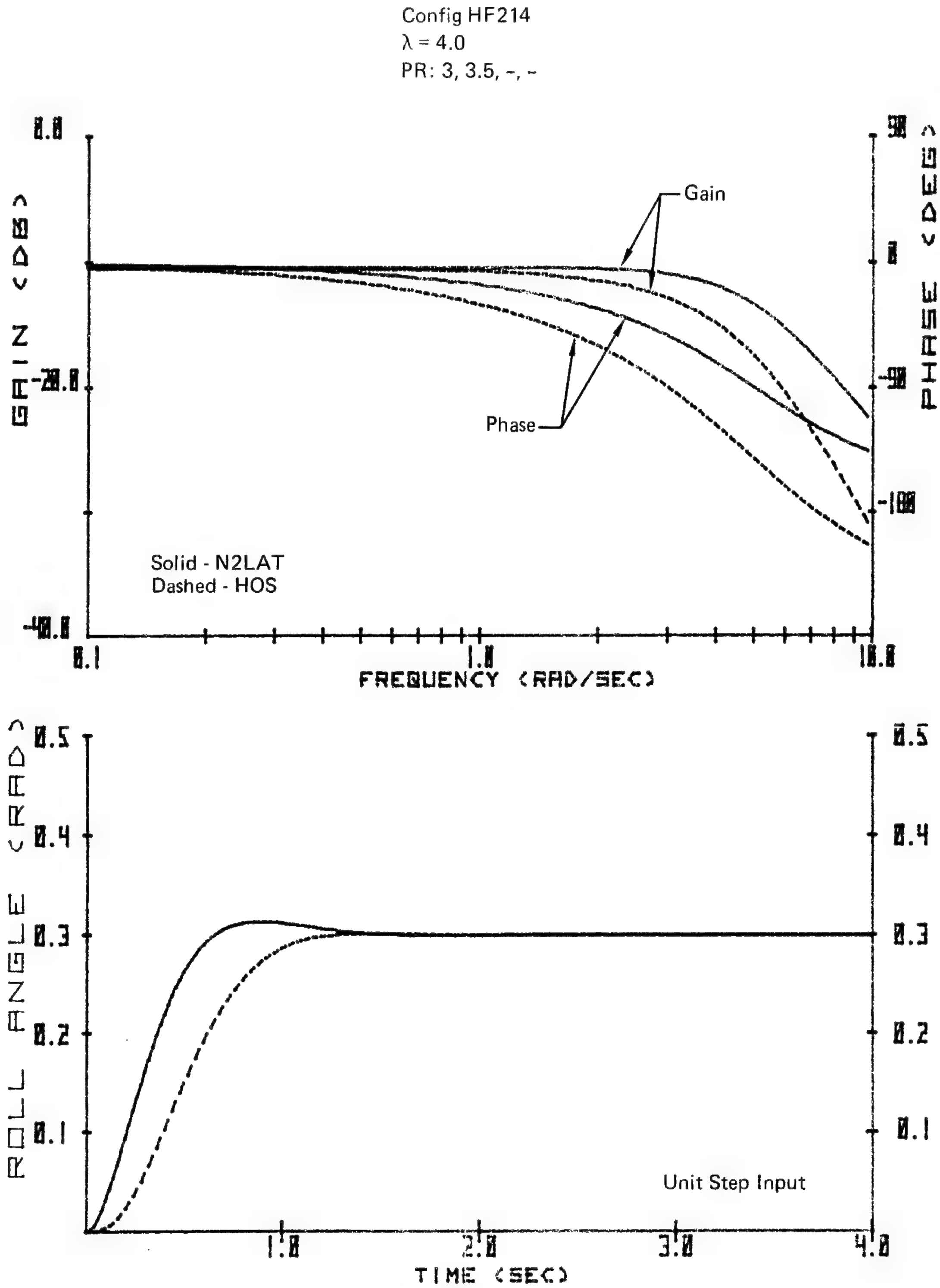


Figure A-30. Frequency and Time Response

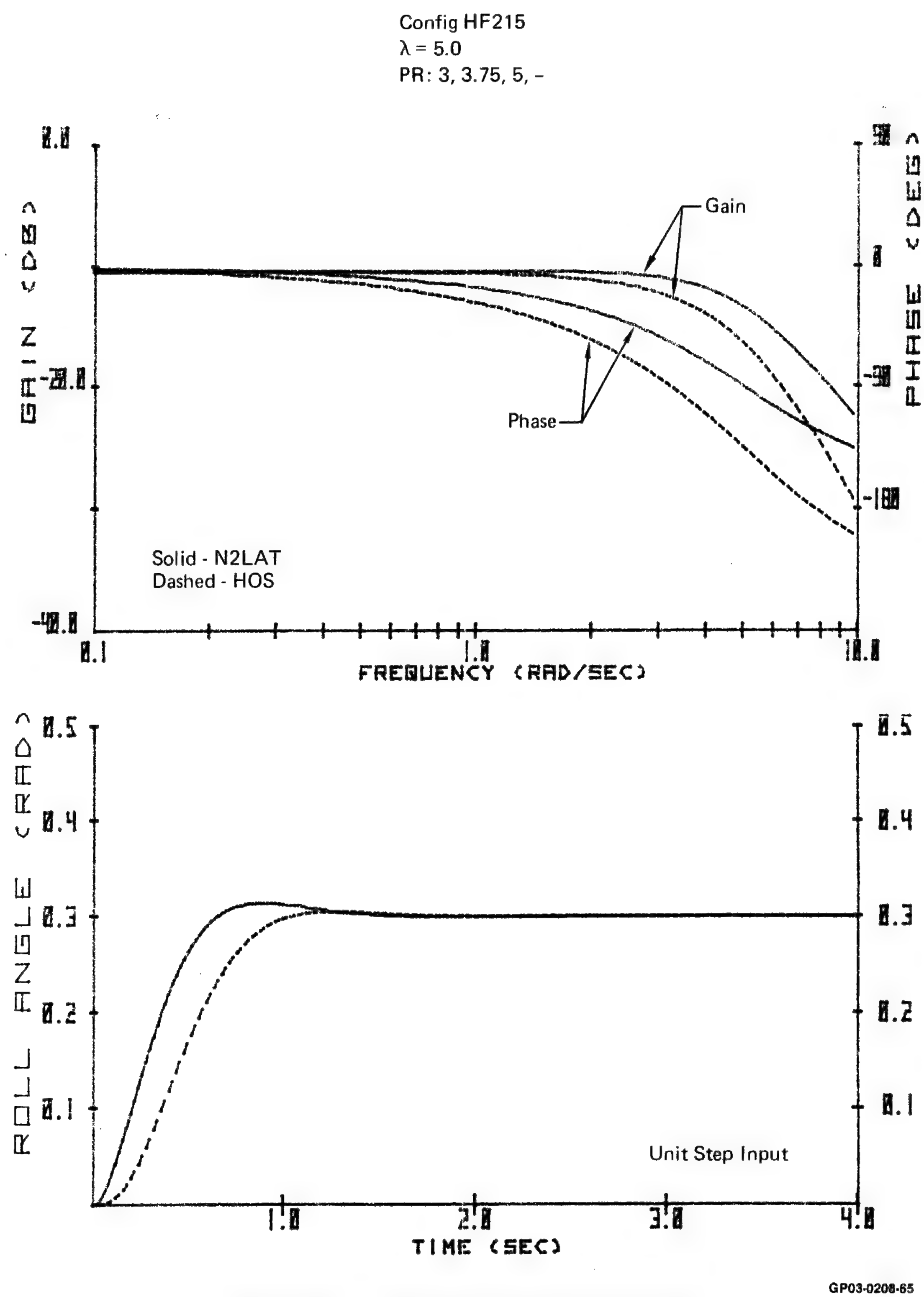


Figure A-31. Frequency and Time Response

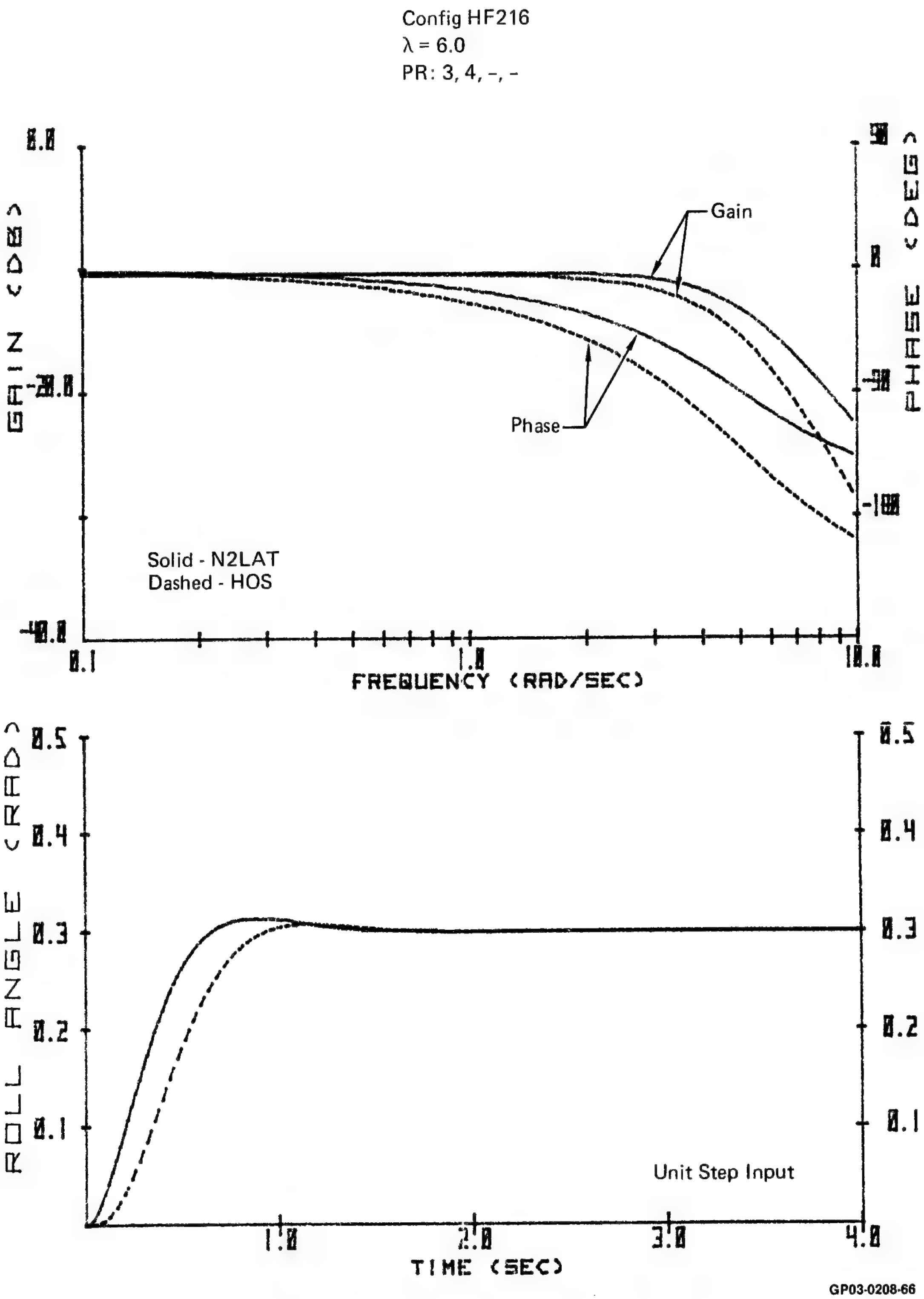


Figure A-32. Frequency and Time Response

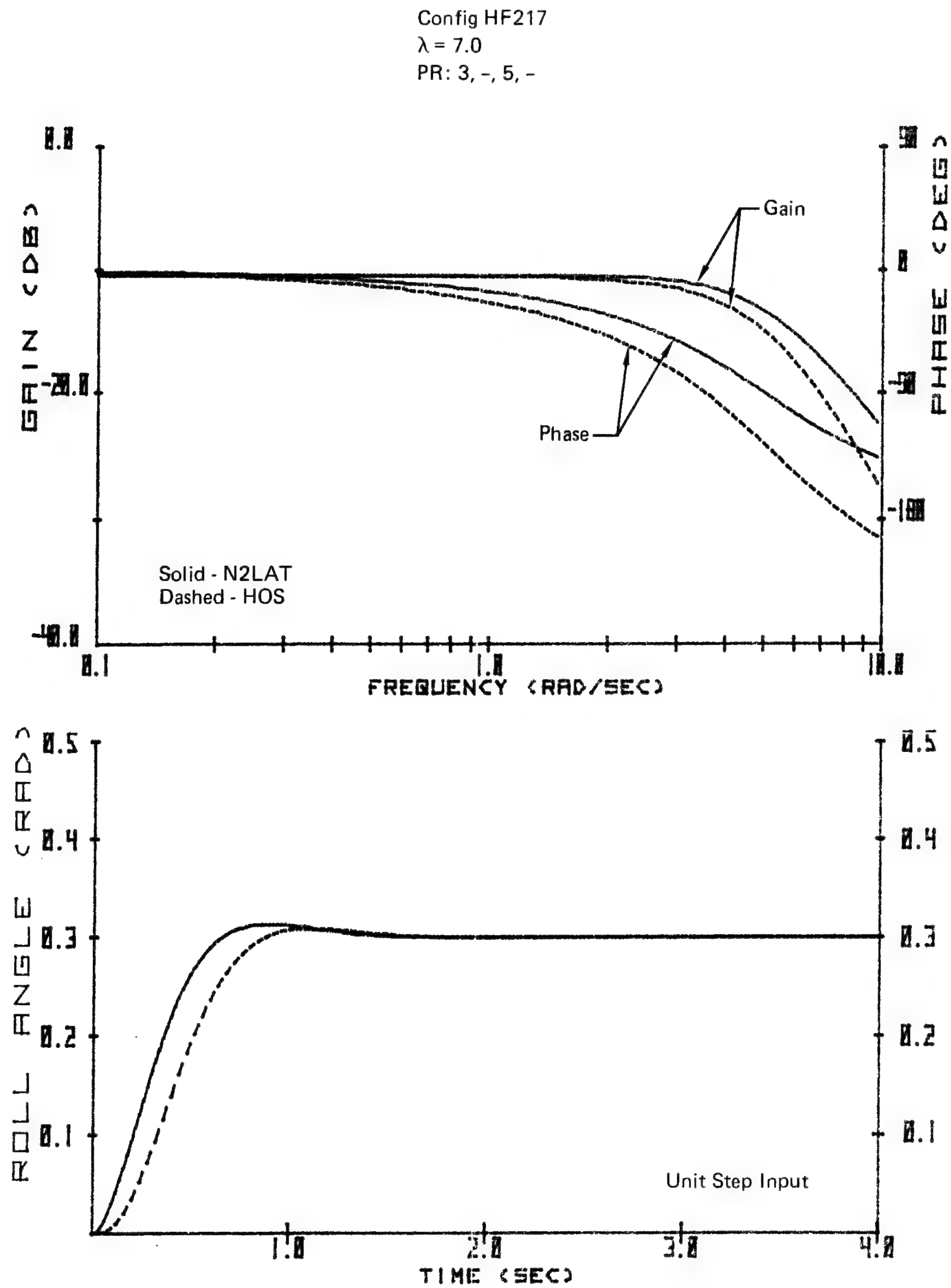


Figure A-33. Frequency and Time Response

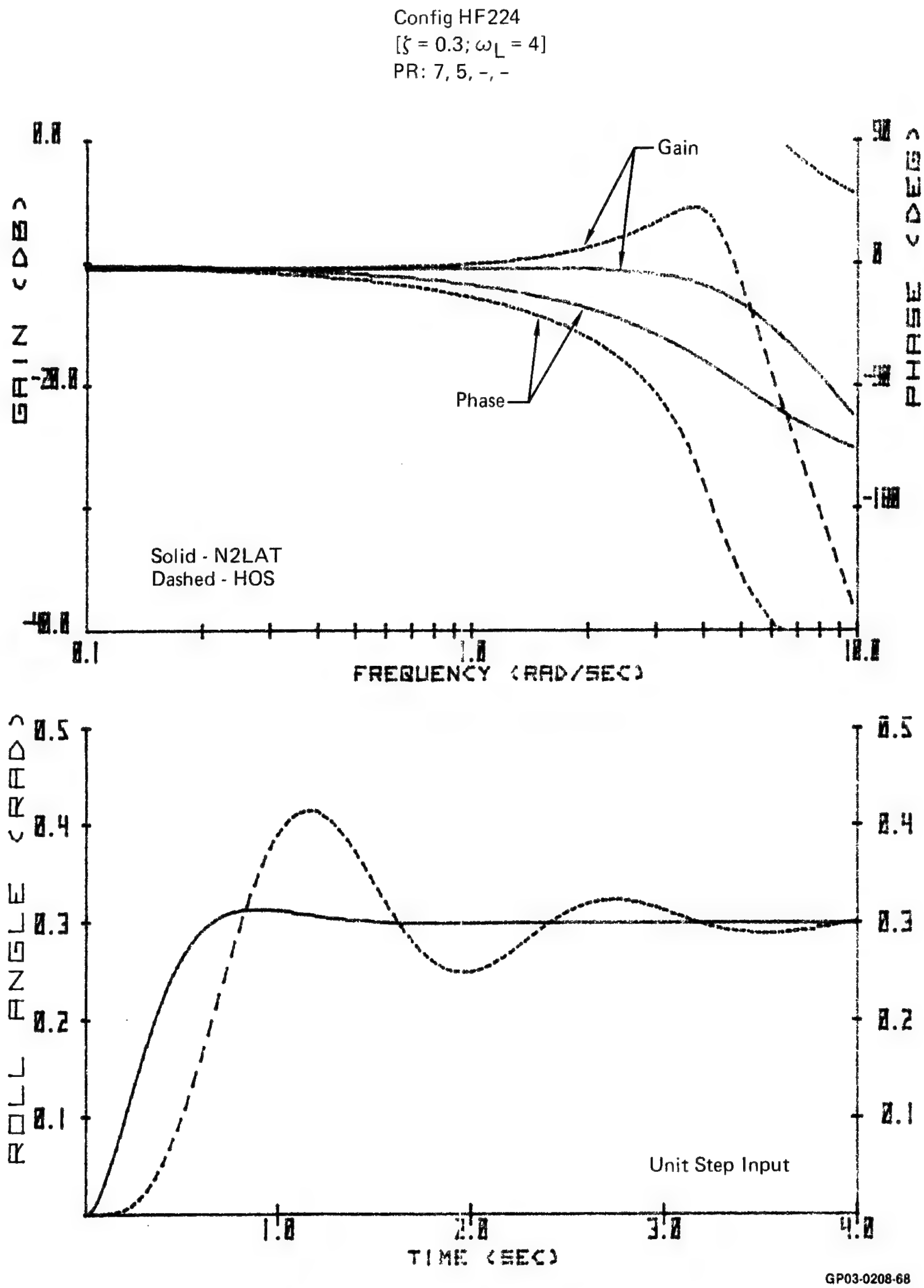


Figure A-34. Frequency and Time Response

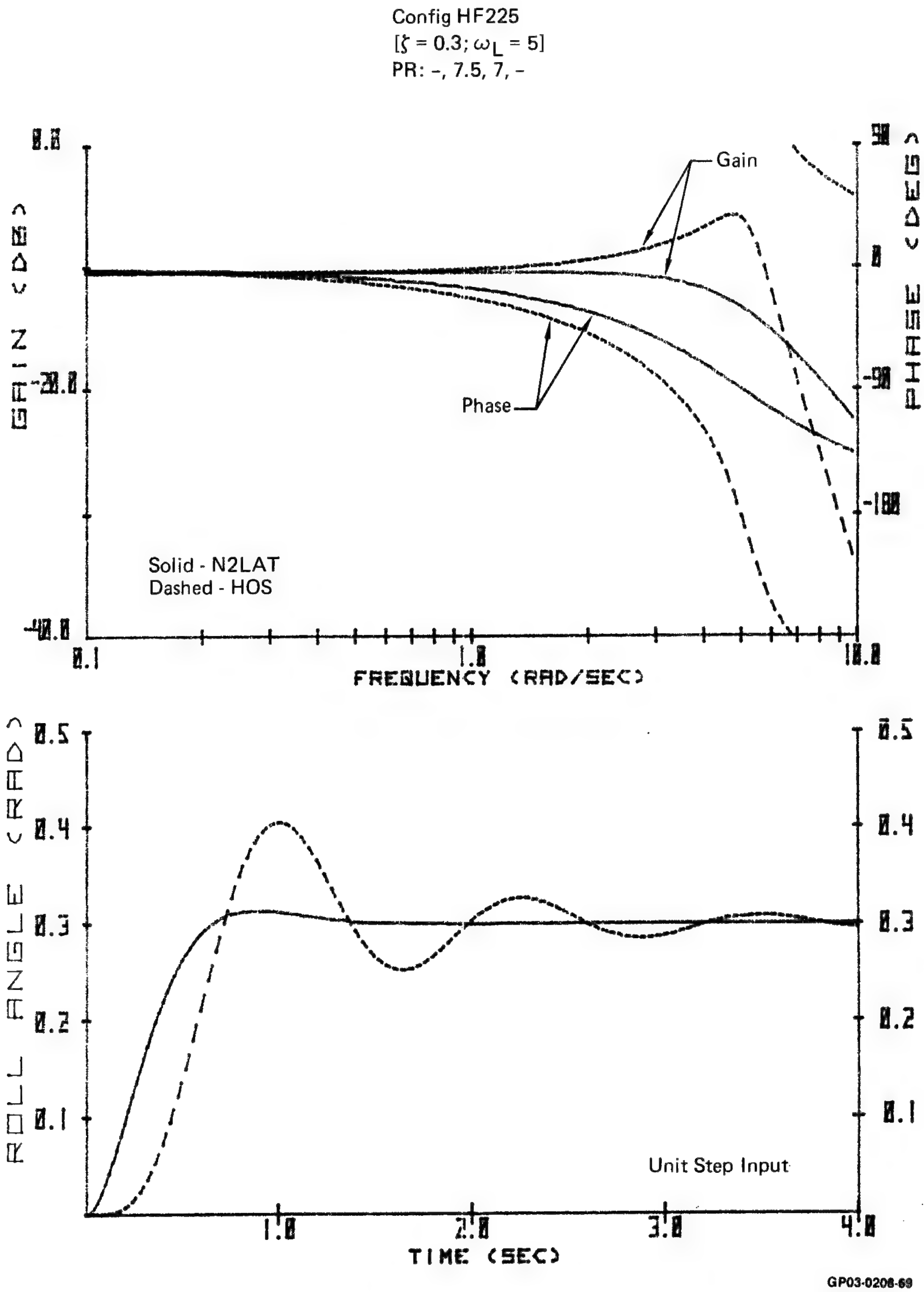


Figure A-35. Frequency and Time Response

Config HF226
[ζ = 0.3; ω_L = 6]
PR: 6, 5.5, –, –

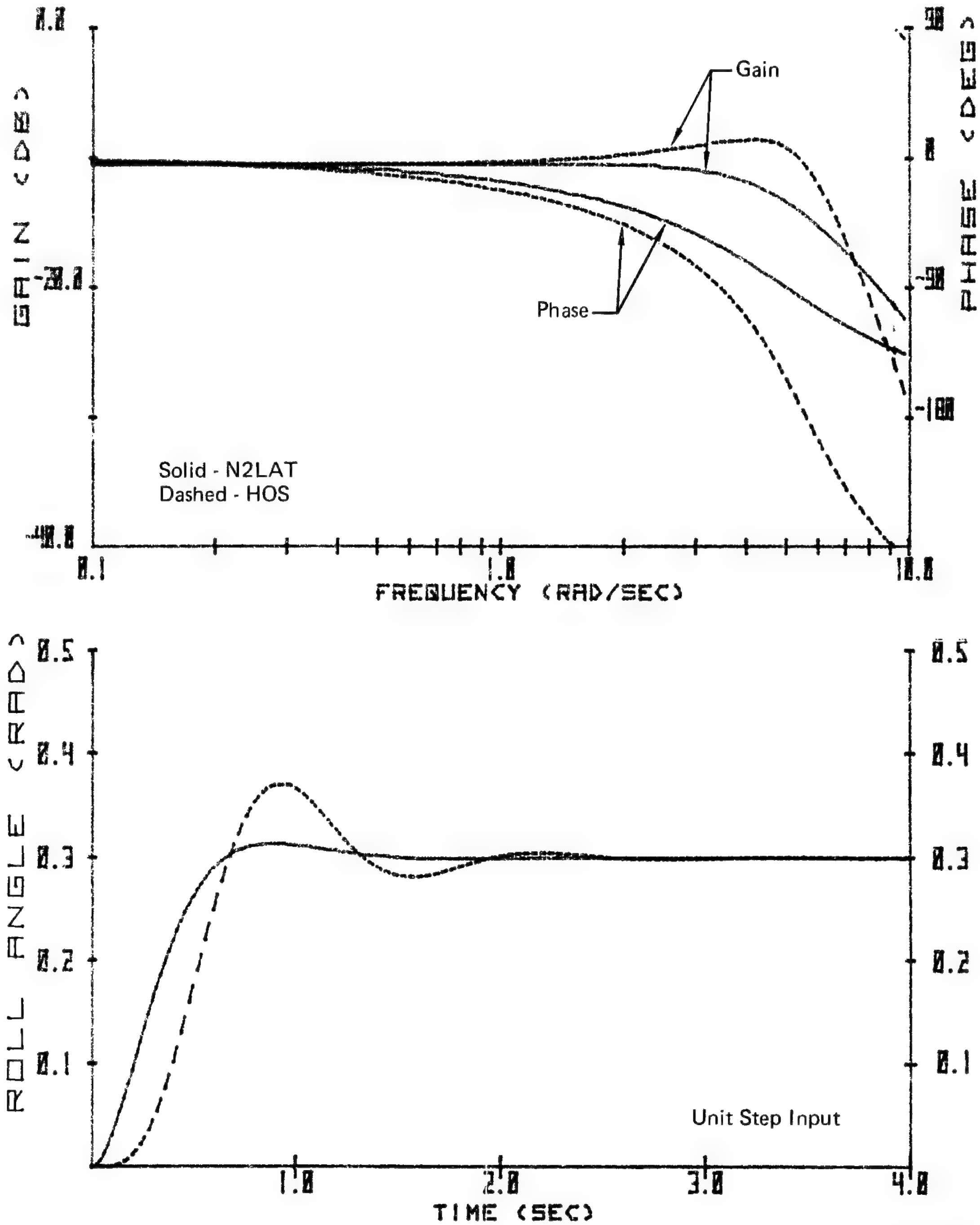
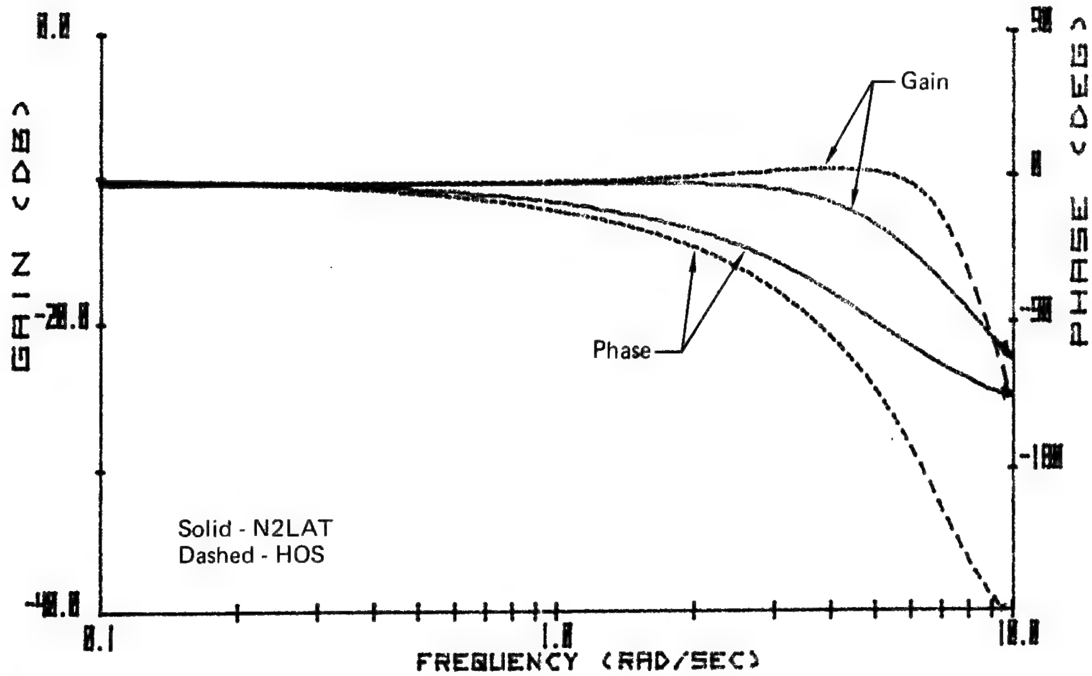


Figure A-36. Frequency and Time Response

Config HF227
[$\zeta = 0.3$; $\omega_L = 7$]
PR: 6, 5.5, 6, -



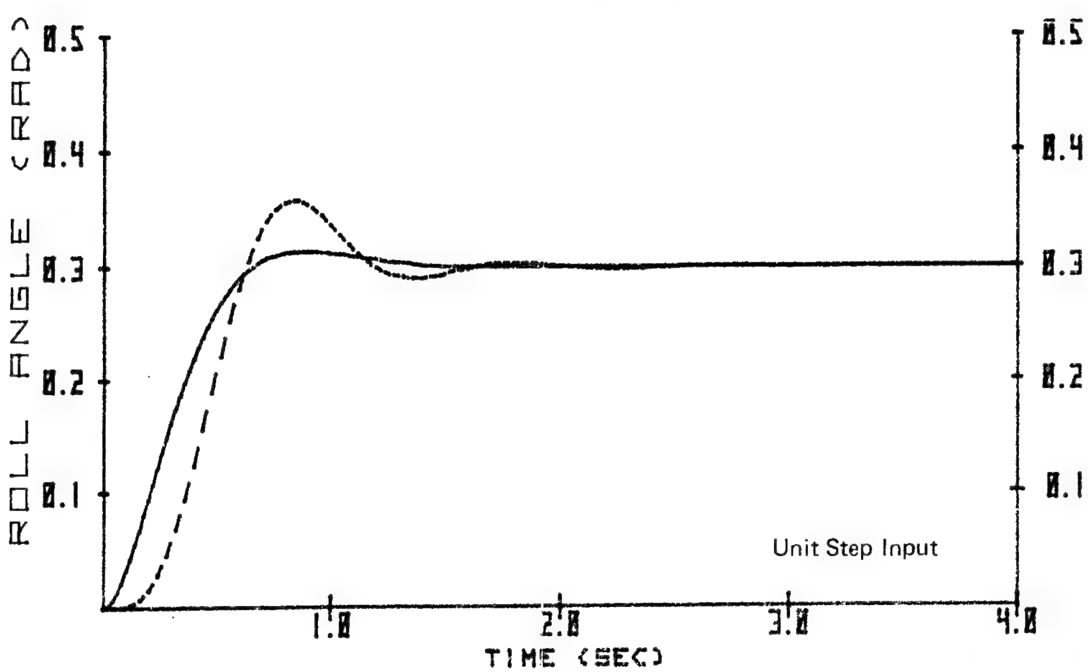


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Figure A-37. Frequency and Time Response

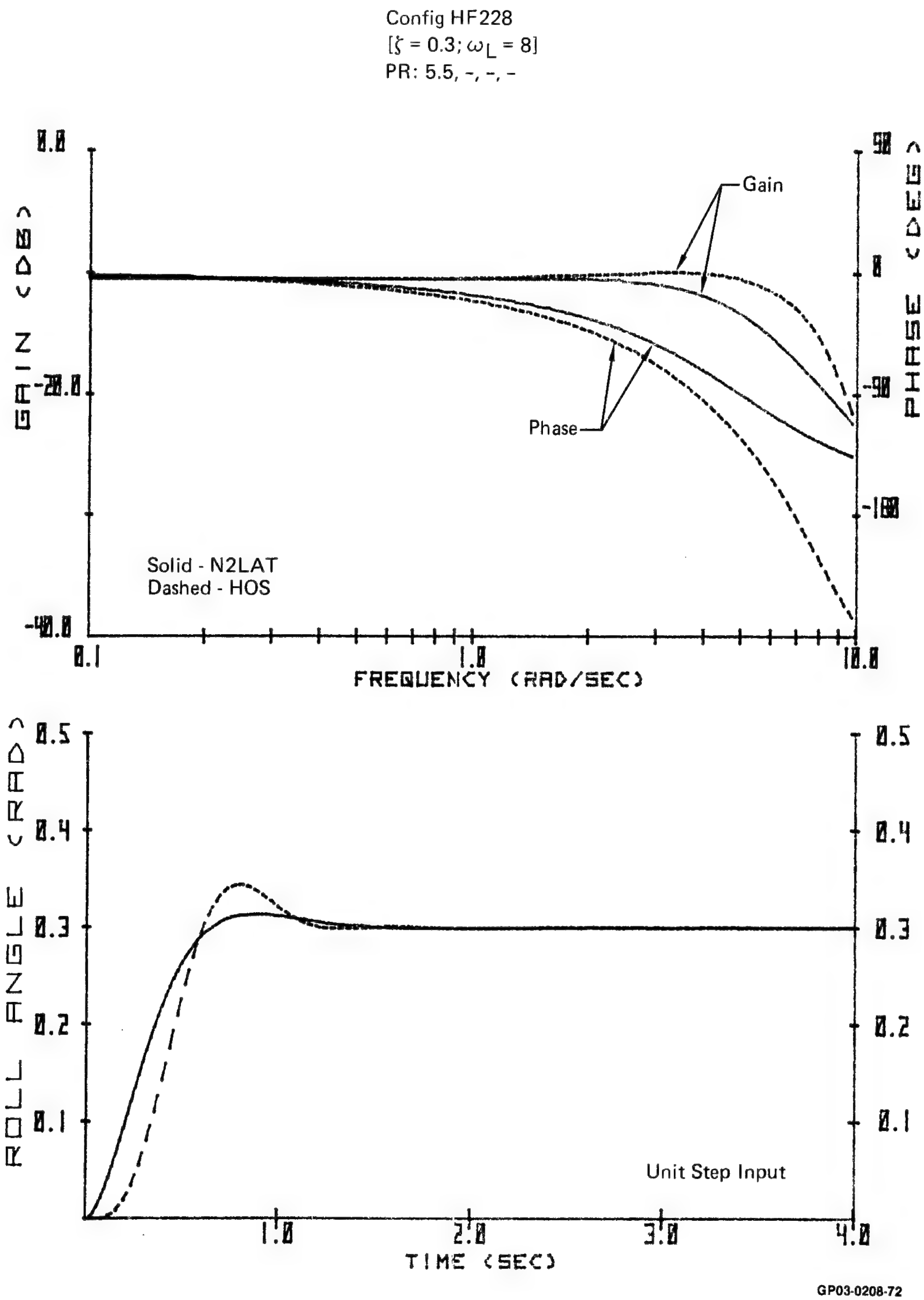

Figure A-38. Frequency and Time Response

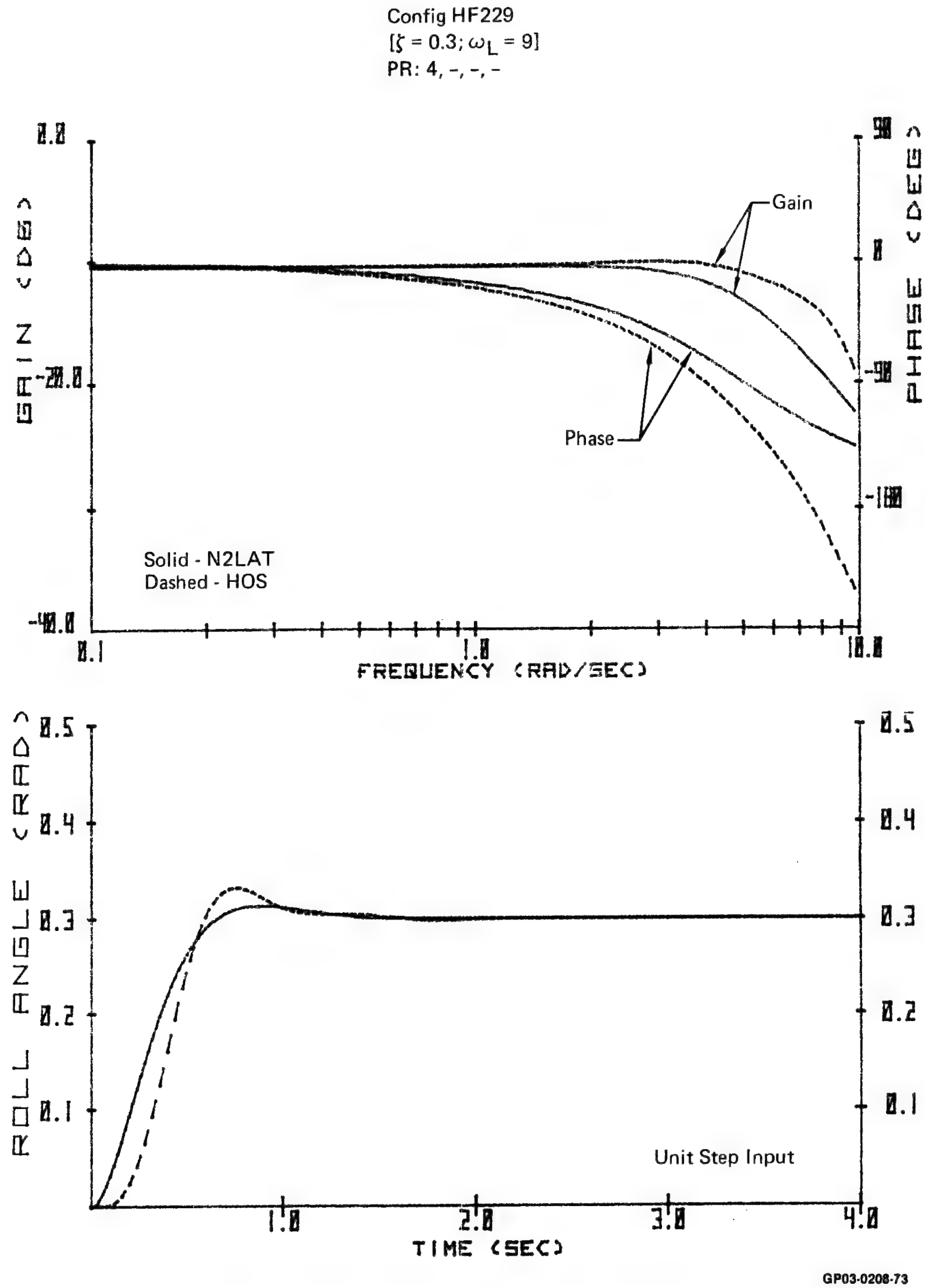

Figure A-39. Frequency and Time Response

Config HF220
[ζ = 0.3; ω_L = 10]
PR: 5, -, -, -

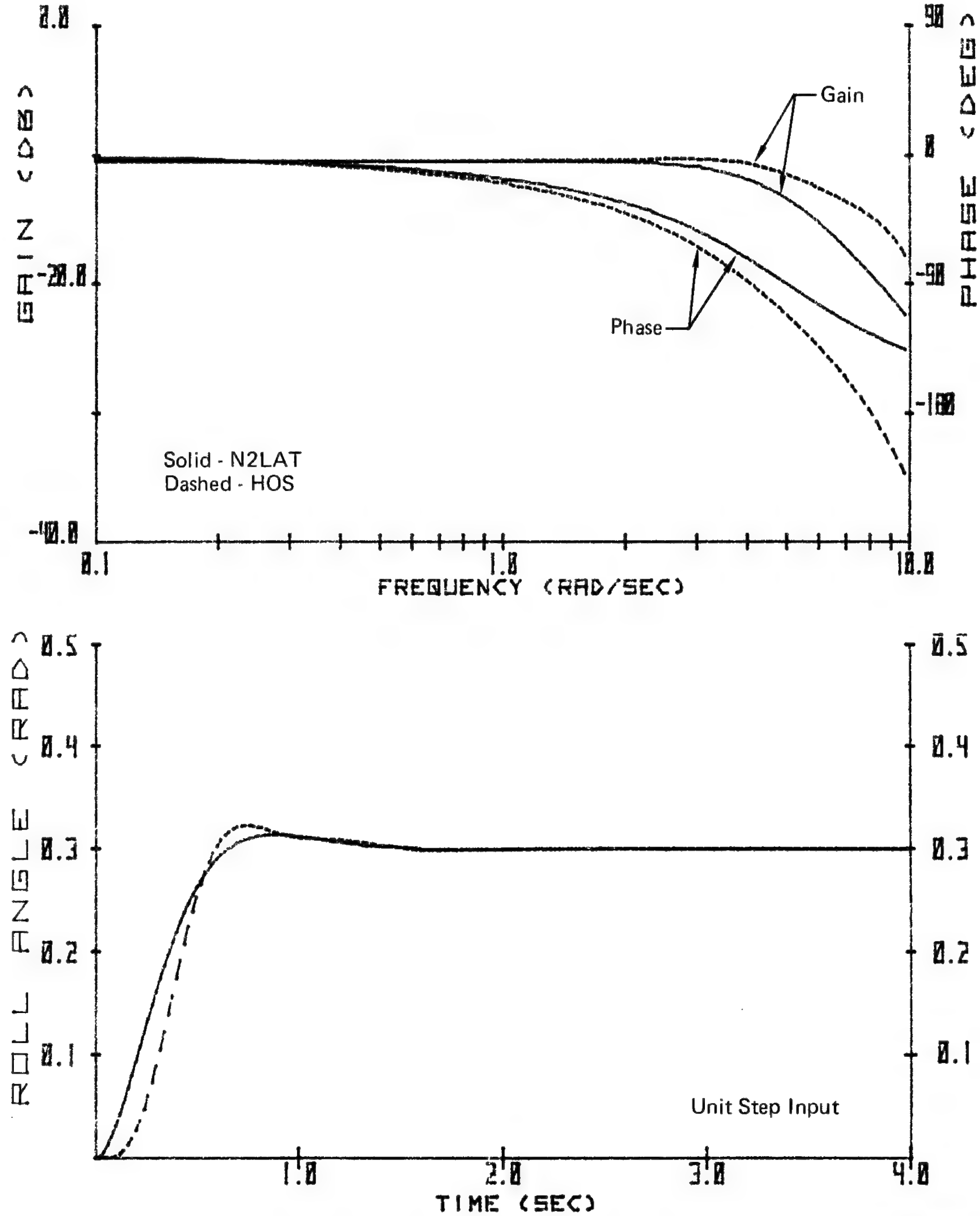

Figure A-40. Frequency and Time Response

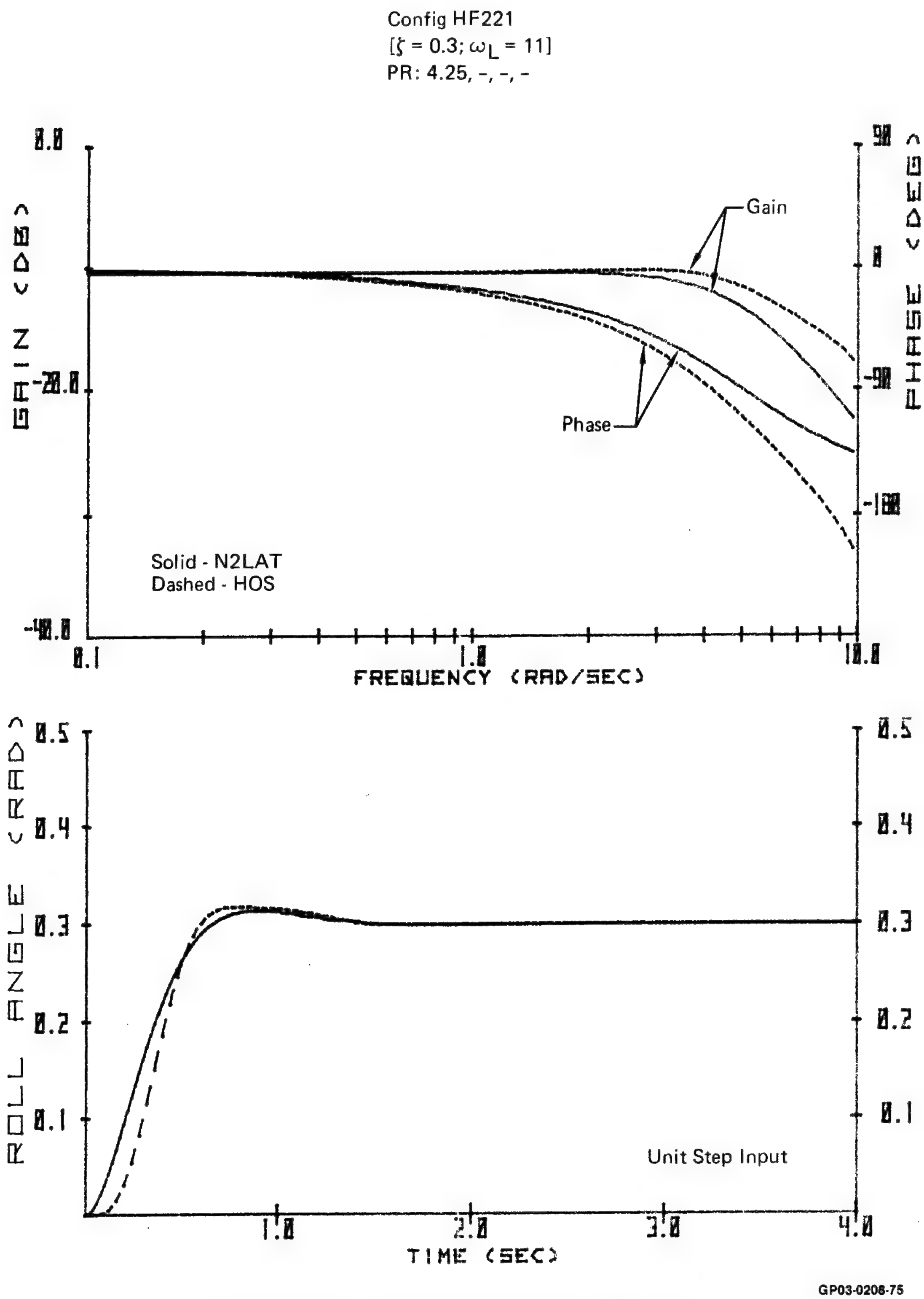

Figure A-41. Frequency and Time Response

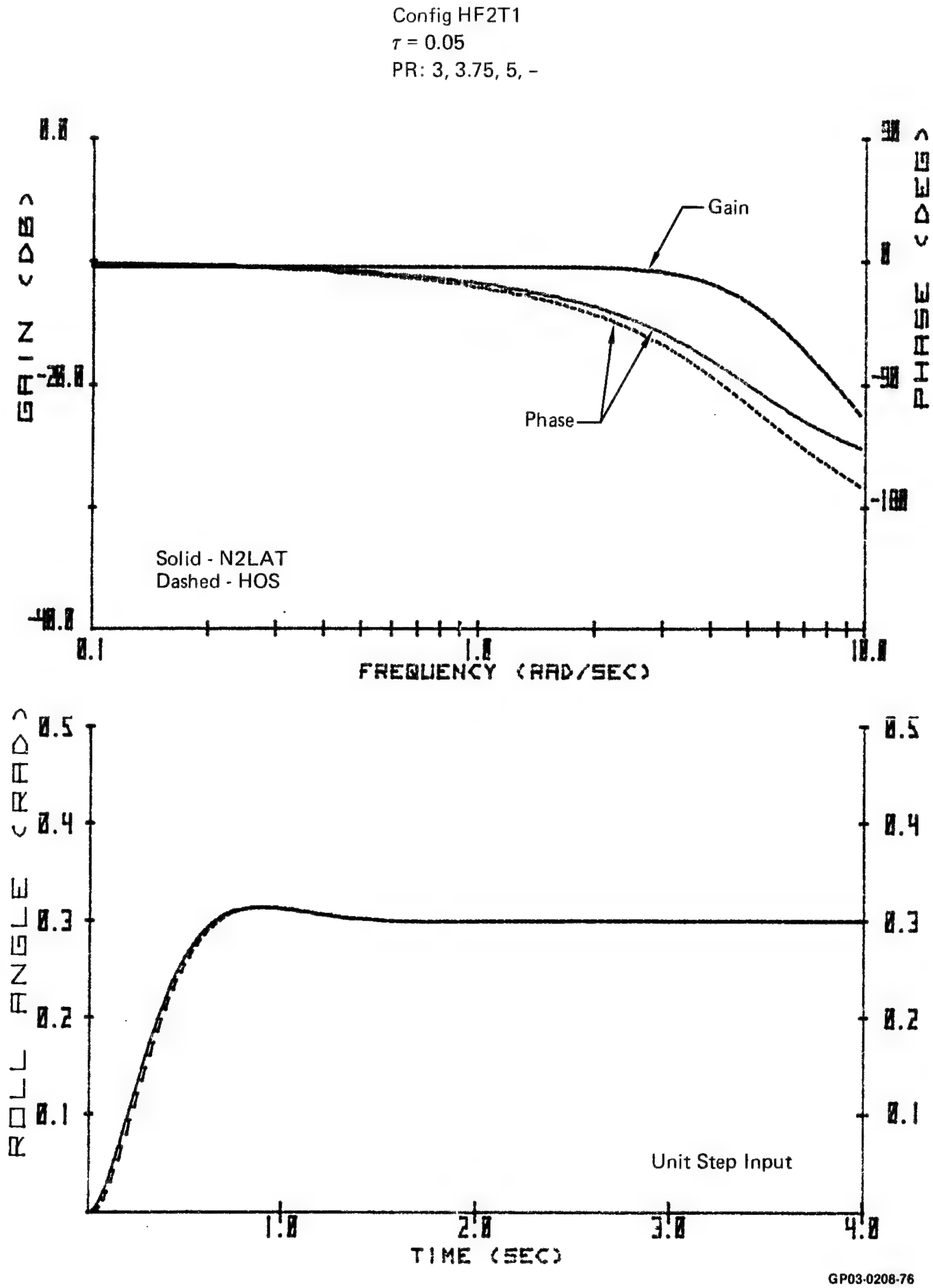

Figure A-42. Frequency and Time Response

Config HF2T2
$\tau = 0.08$
PR: 2.5, 5, –, –

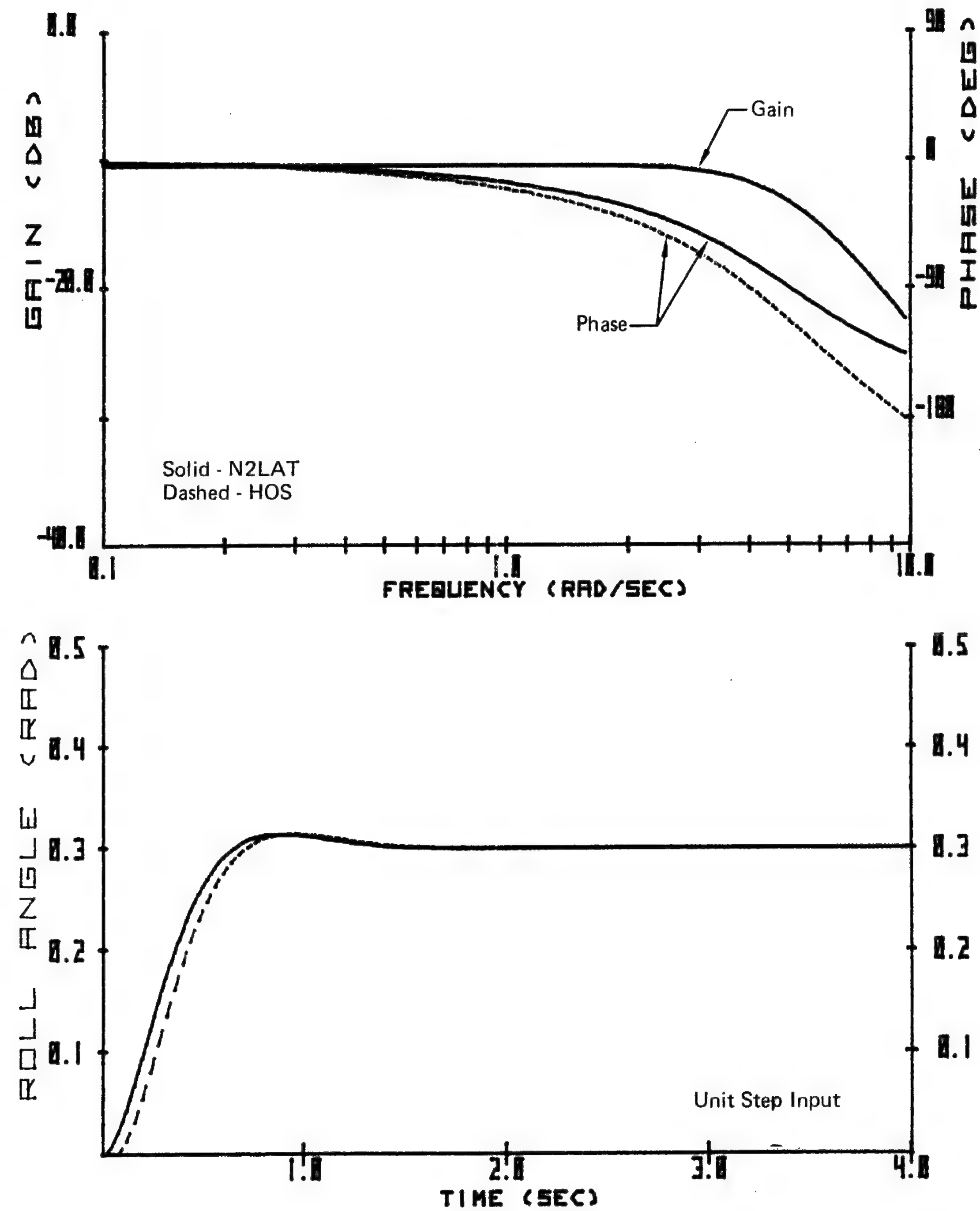

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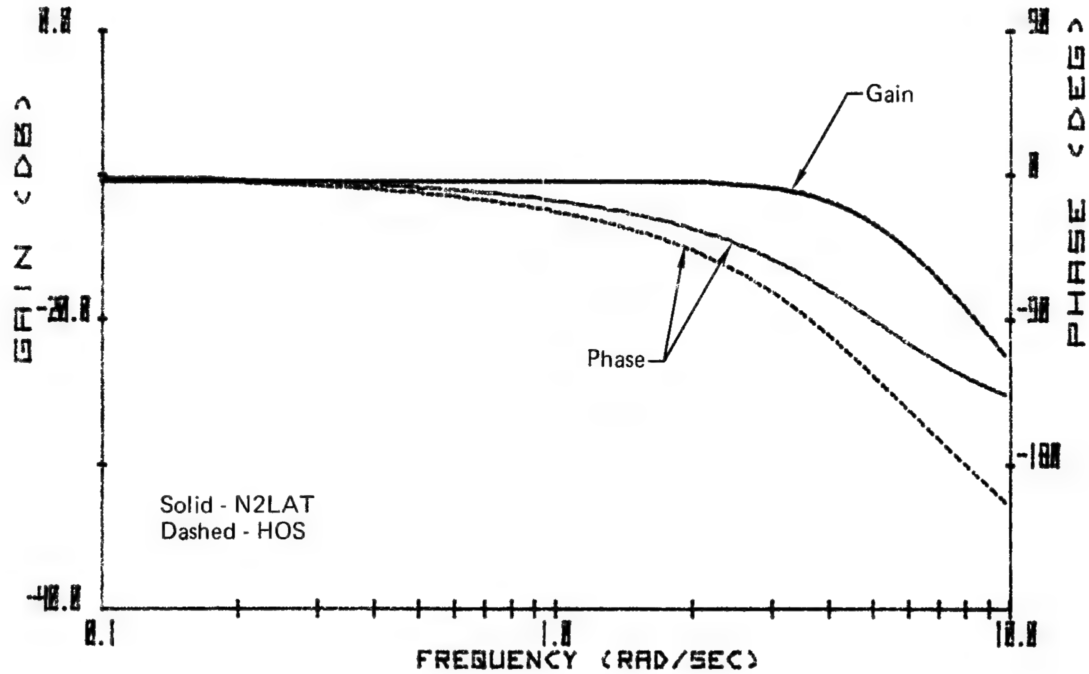
Figure A-43. Frequency and Time Response

Config HF2T3
$\tau = 0.12$
PR: 3, 5, -, -



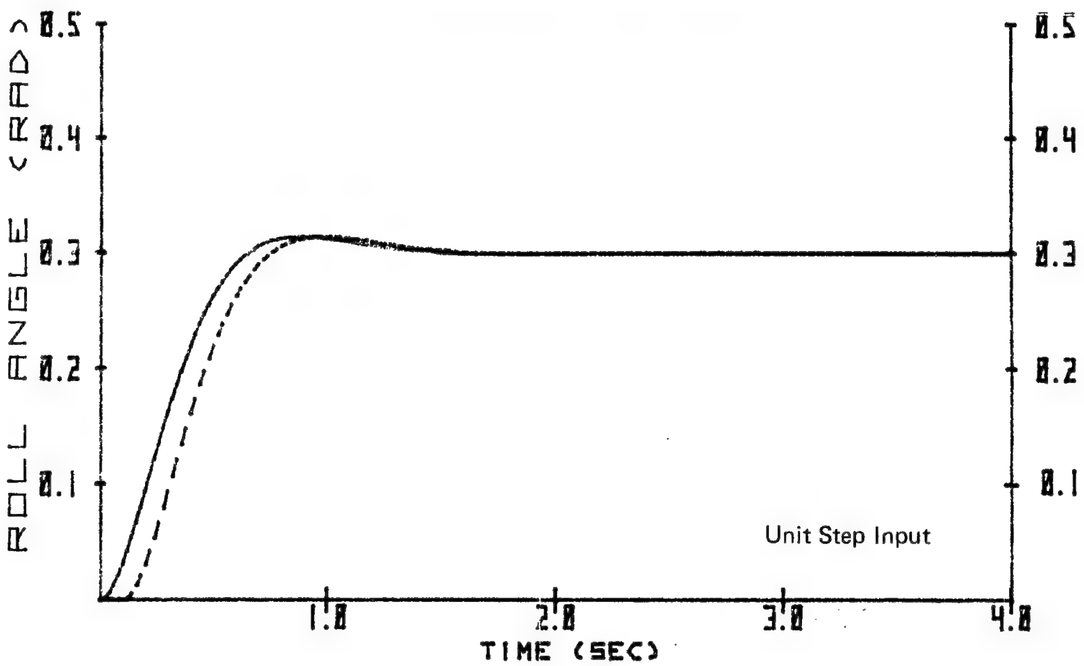


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Figure A-44. Frequency and Time Response

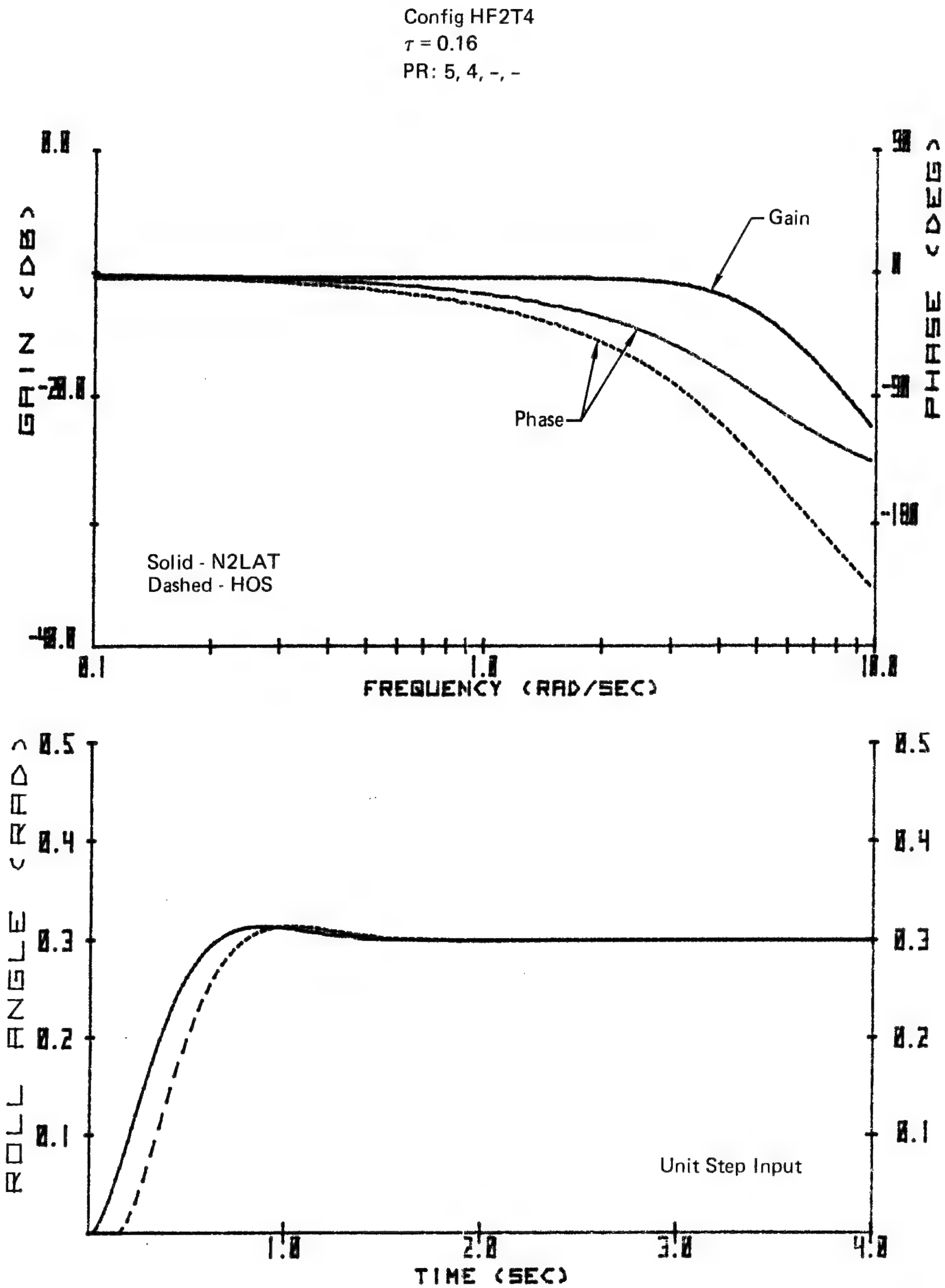

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Figure A-45. Frequency and Time Response

Config HF2T5
$\tau = 0.2$
PR: 5, –, –, -

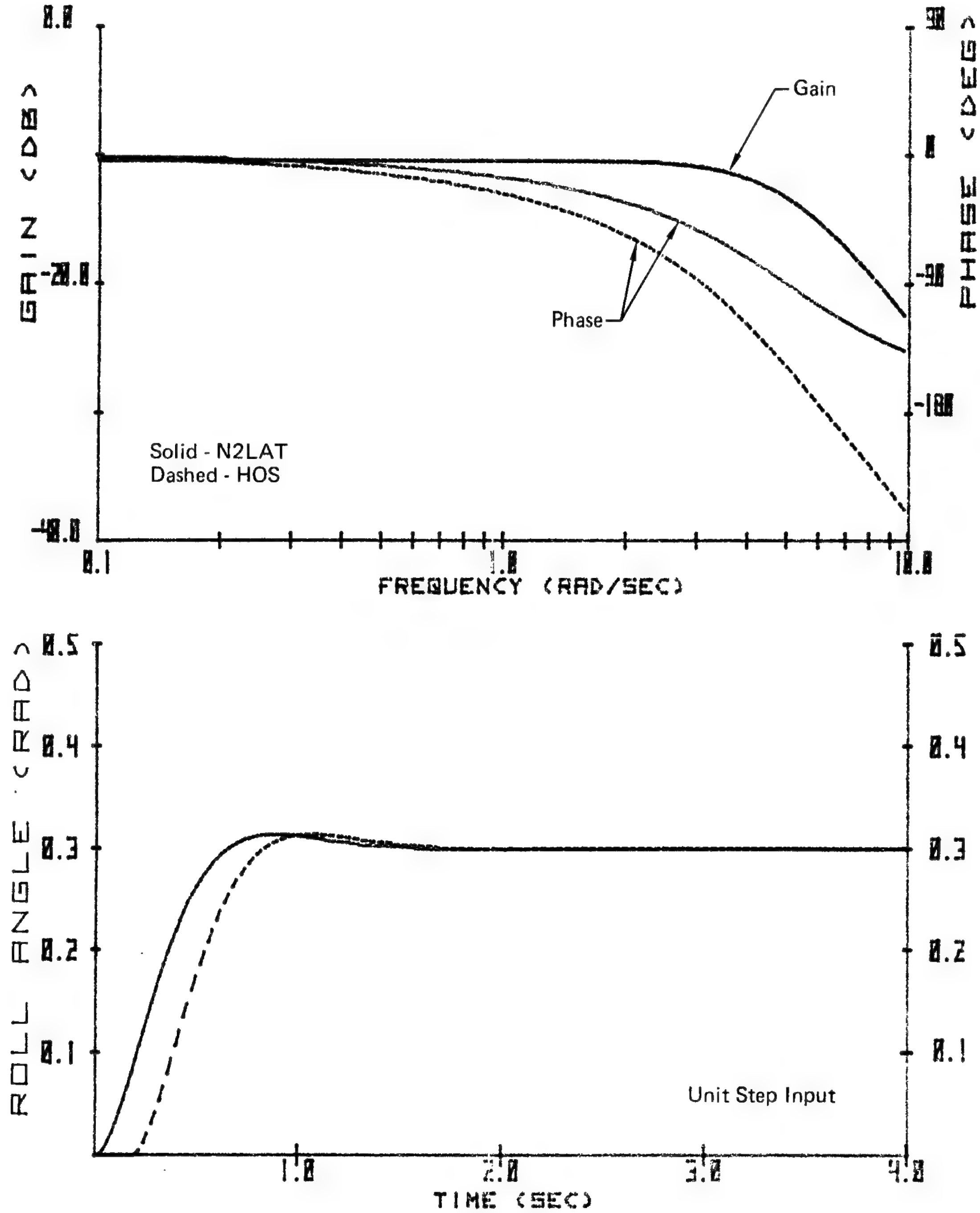

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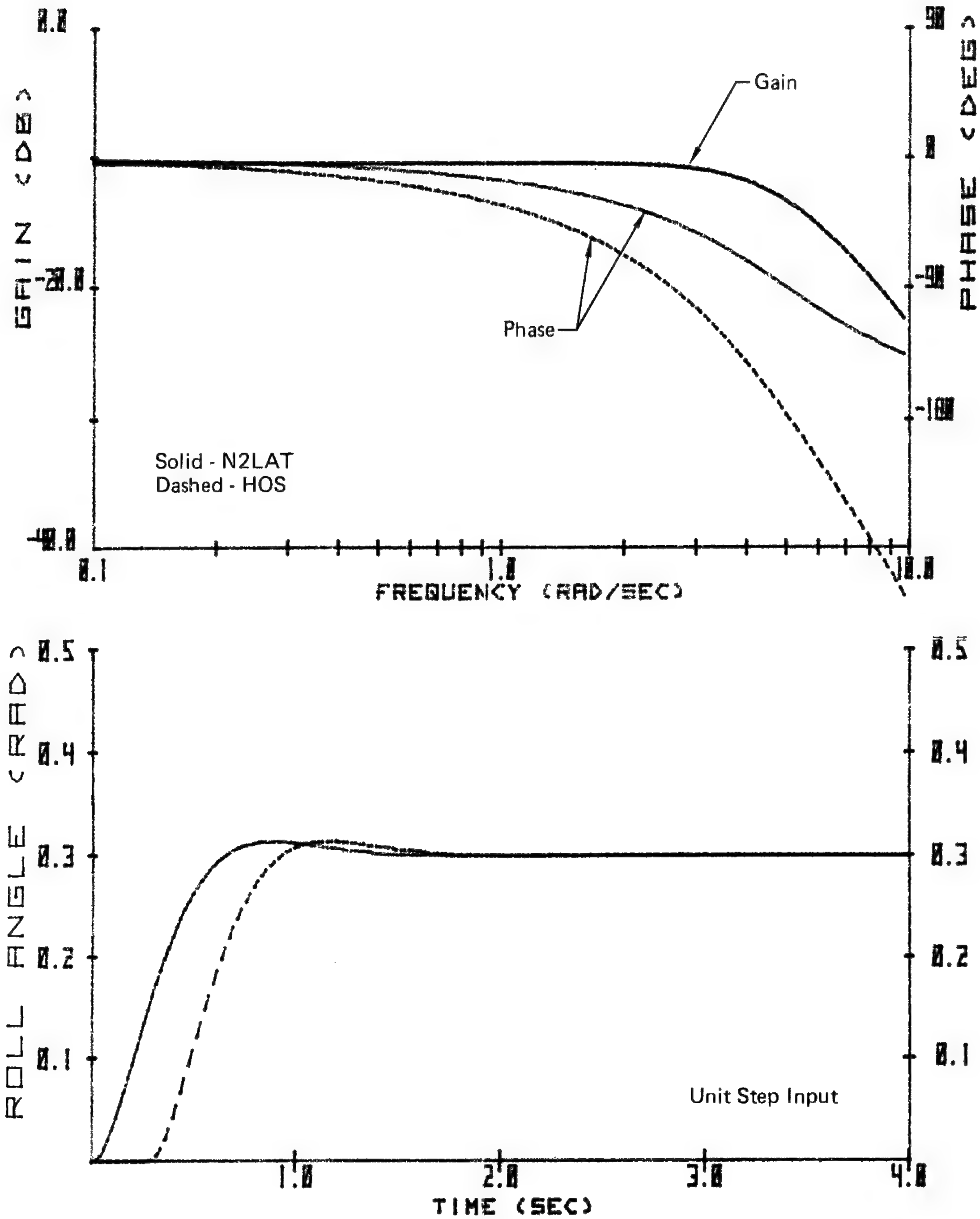
Figure A-46. Frequency and Time Response

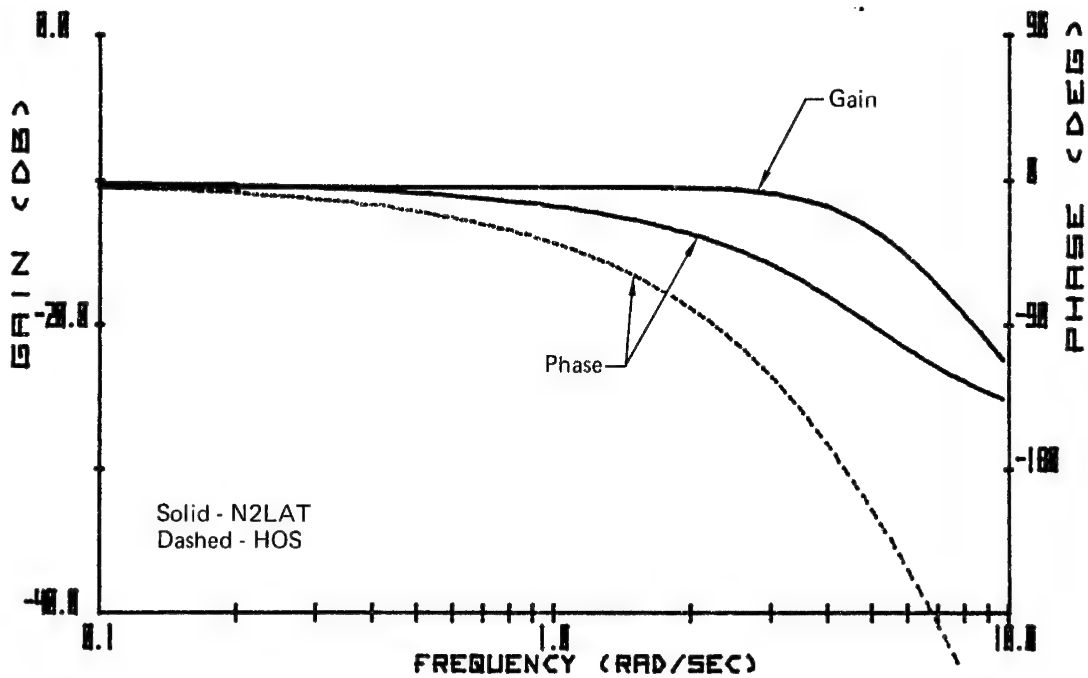
Config HF2T6
$\tau = 0.3$
PR: 6, –, –, –



GP03-0208-81

Figure A-47. Frequency and Time Response

Config HF2T7
$\tau = 0.4$
PR: 8.5, -, -, -



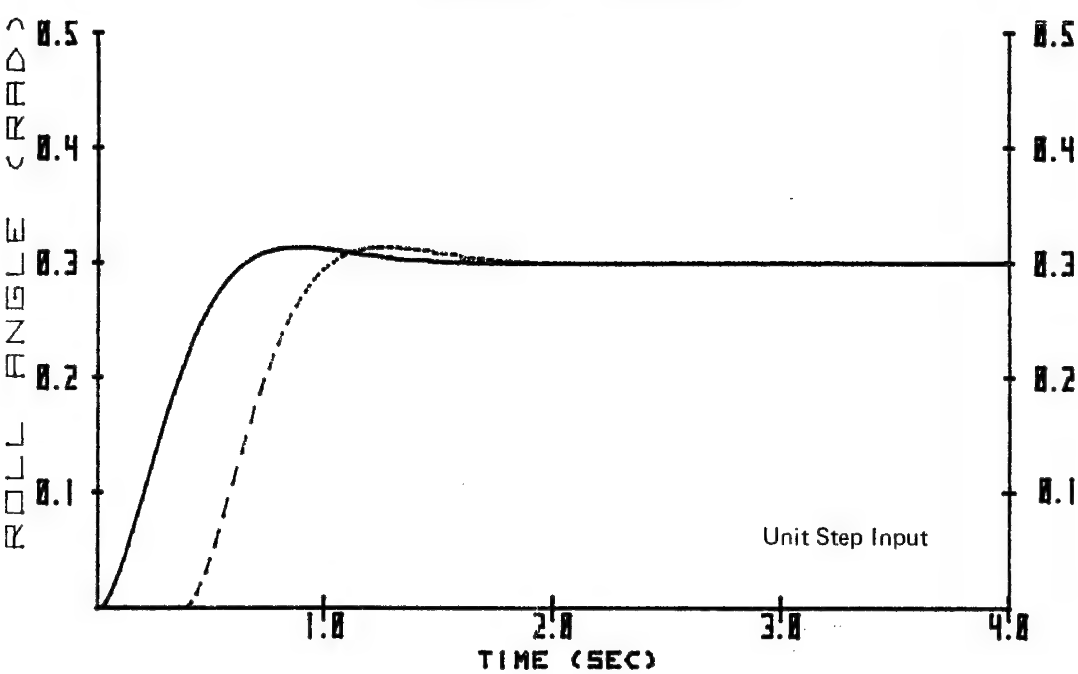


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Figure A-48. Frequency and Time Response

Config LF221
[$\zeta = 0.2; \omega_L = 0.1$]/[$\zeta = 0.7; \omega_L = 0.1$]
PR: 3, -, -, -

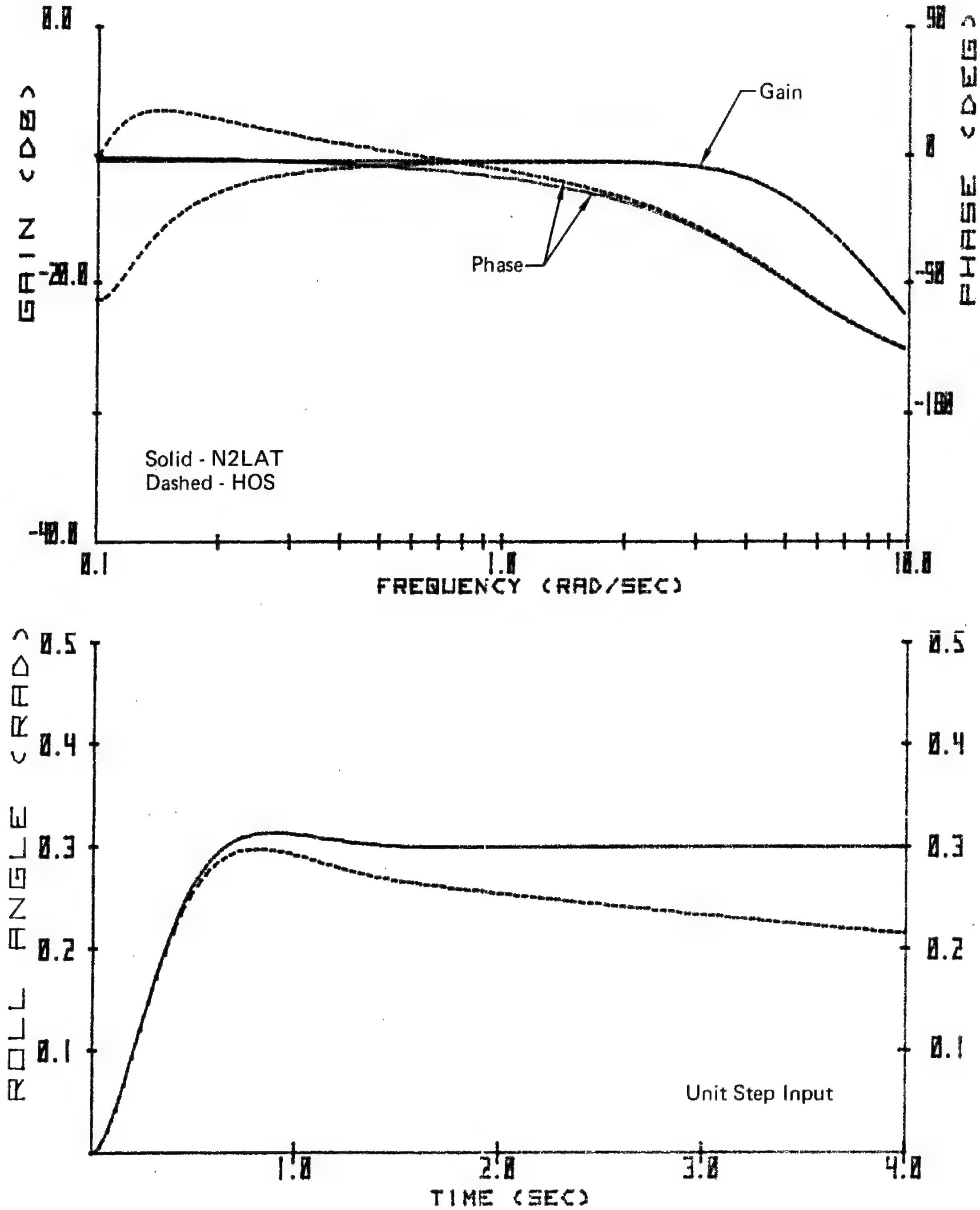

Figure A-49. Frequency and Time Response

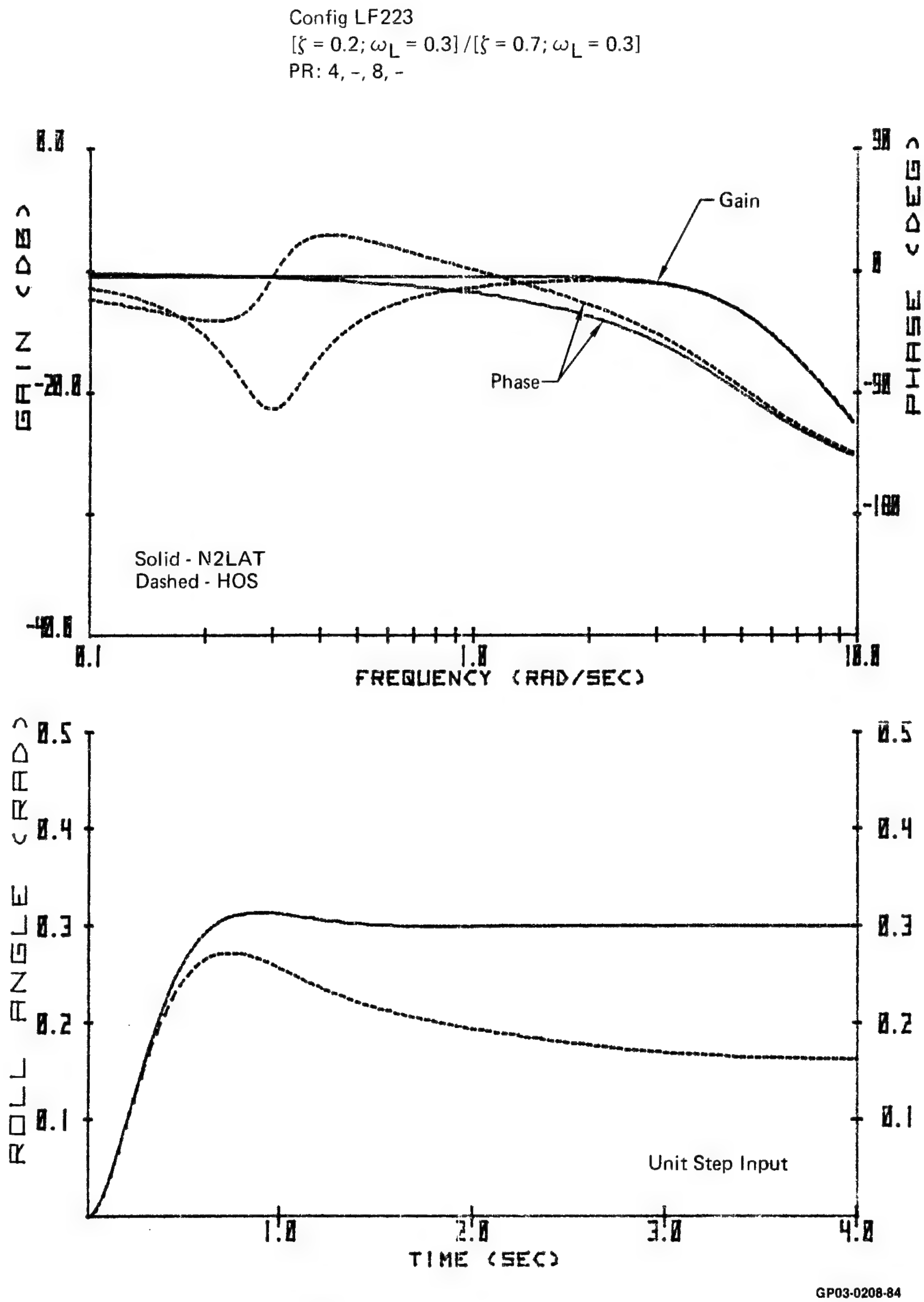

Figure A-50. Frequency and Time Response

Config LF225
[ζ = 0.2; ω_L = 0.5] / [ζ = 0.7; ω_L = 0.5]
PR: 6, -, -, -

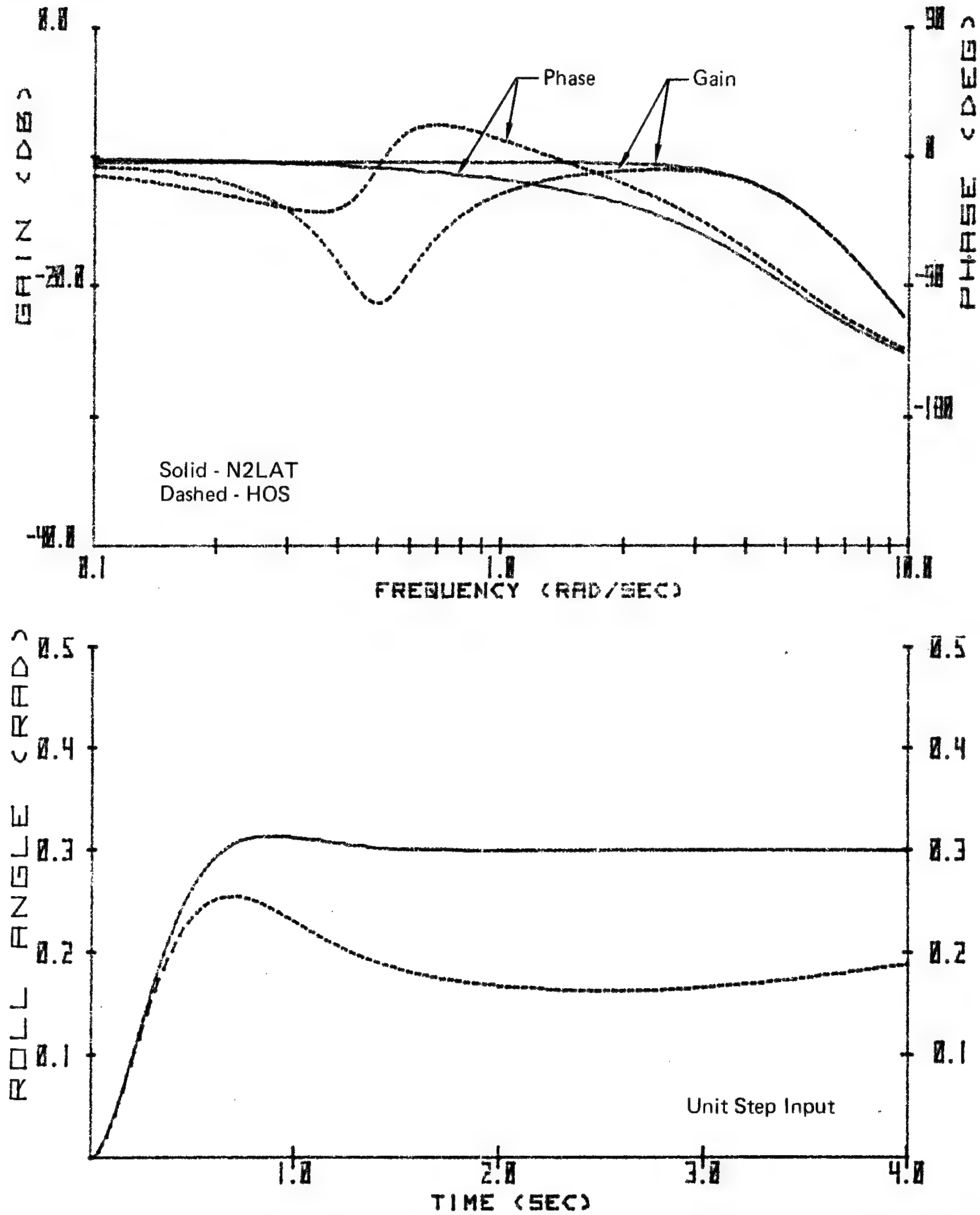

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Figure A-51. Frequency and Time Response

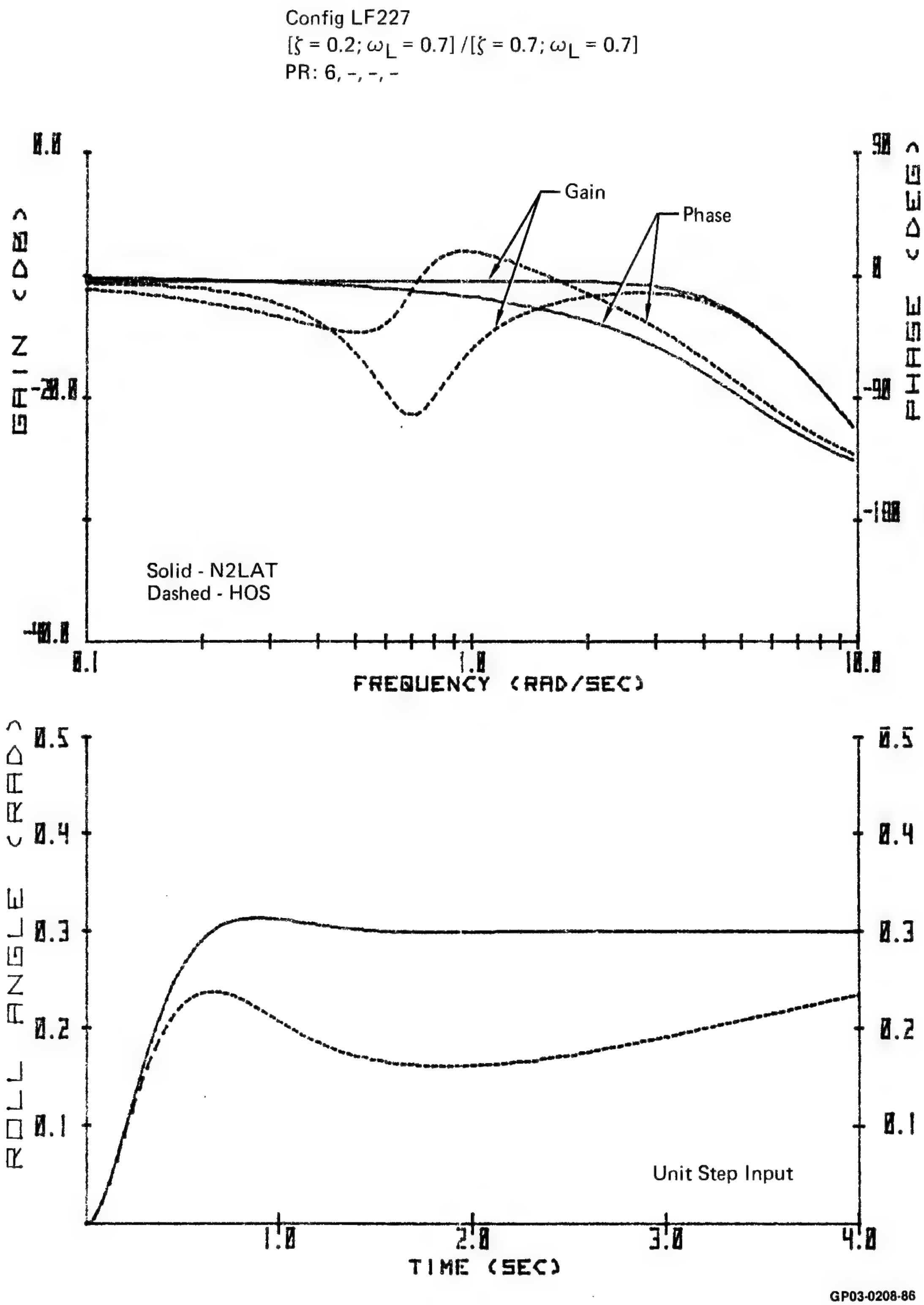

Figure A-52. Frequency and Time Response

Config G120
K = 0.2 $\tau = 0$
PR: 7, -, -, -

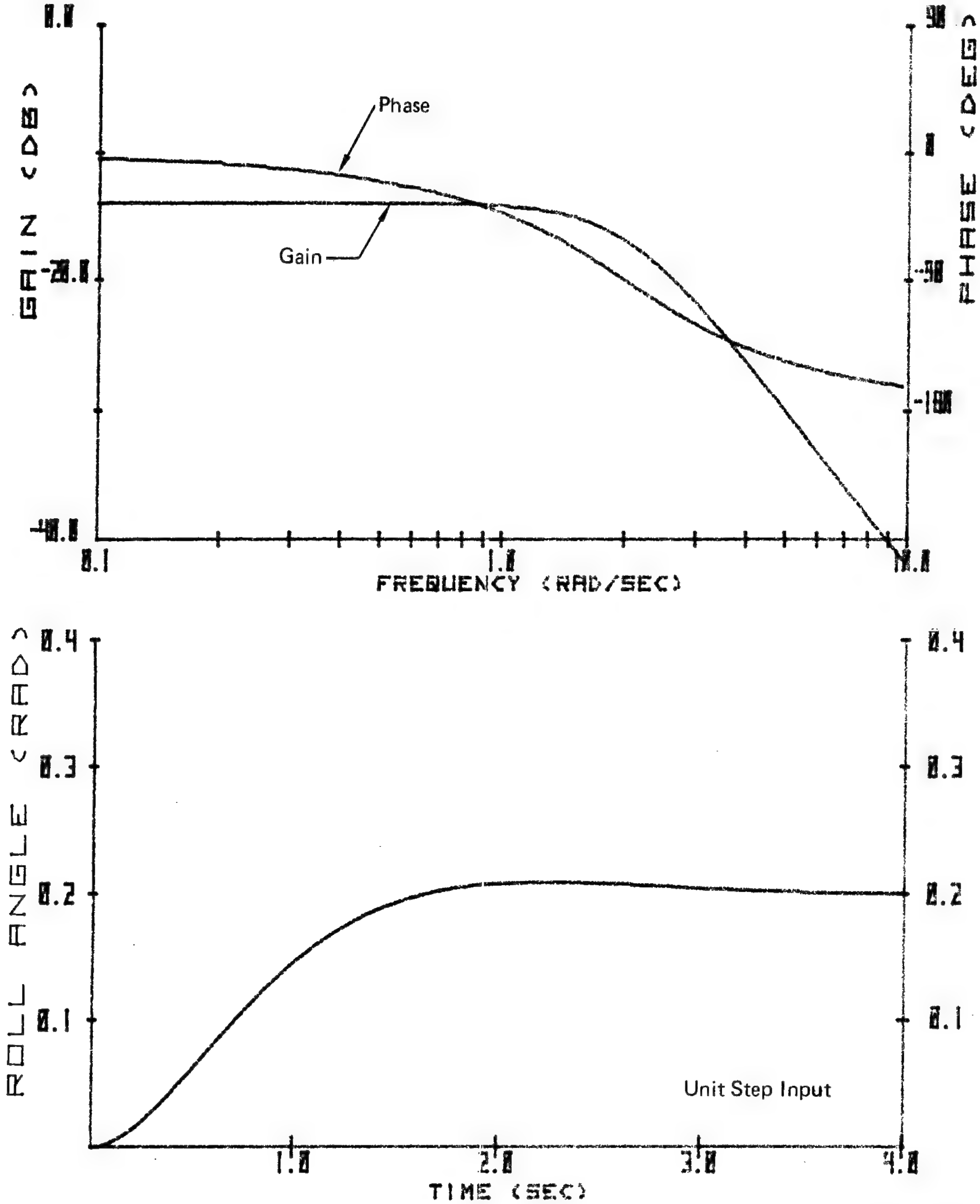

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Figure A-53. Frequency and Time Response

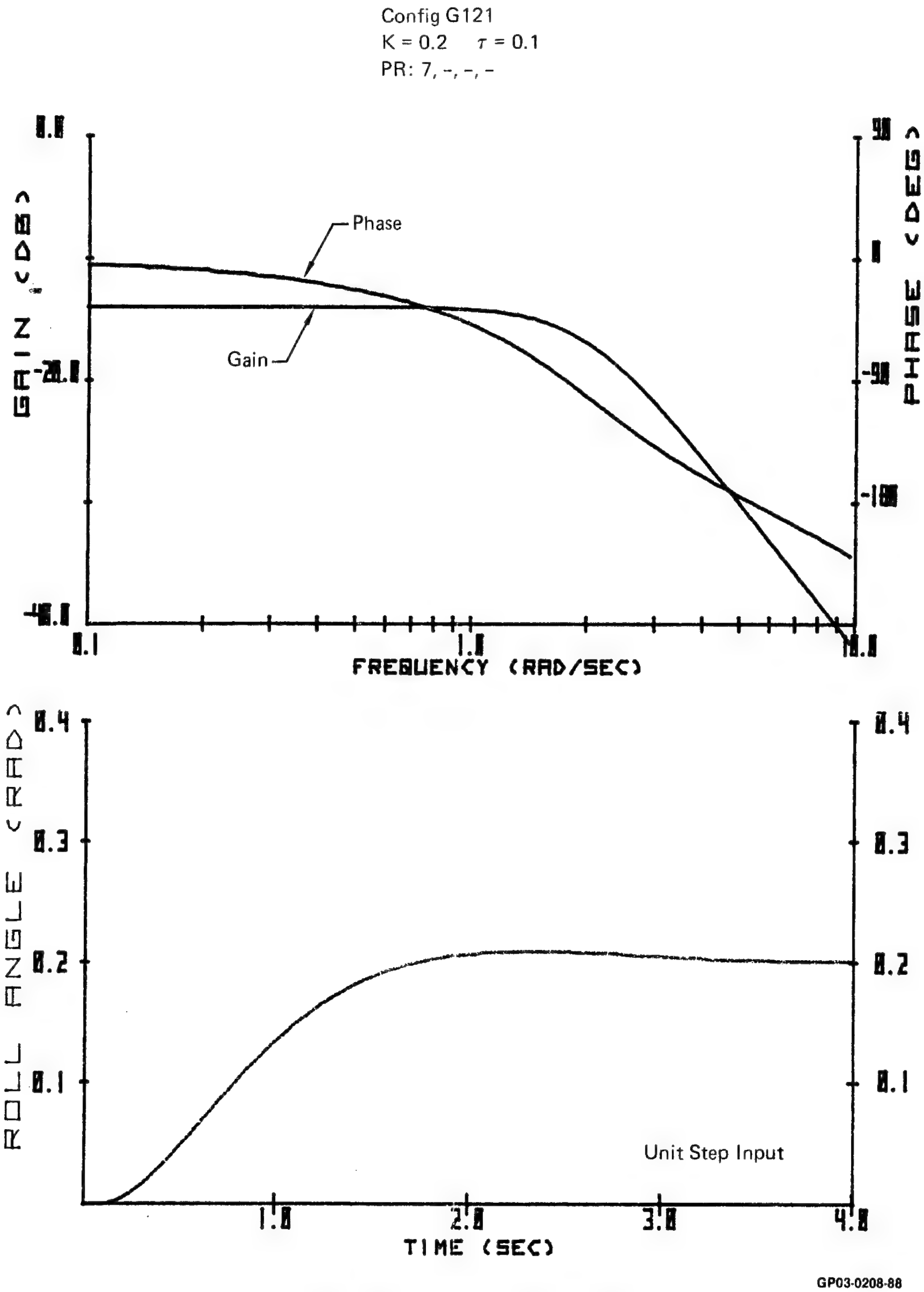
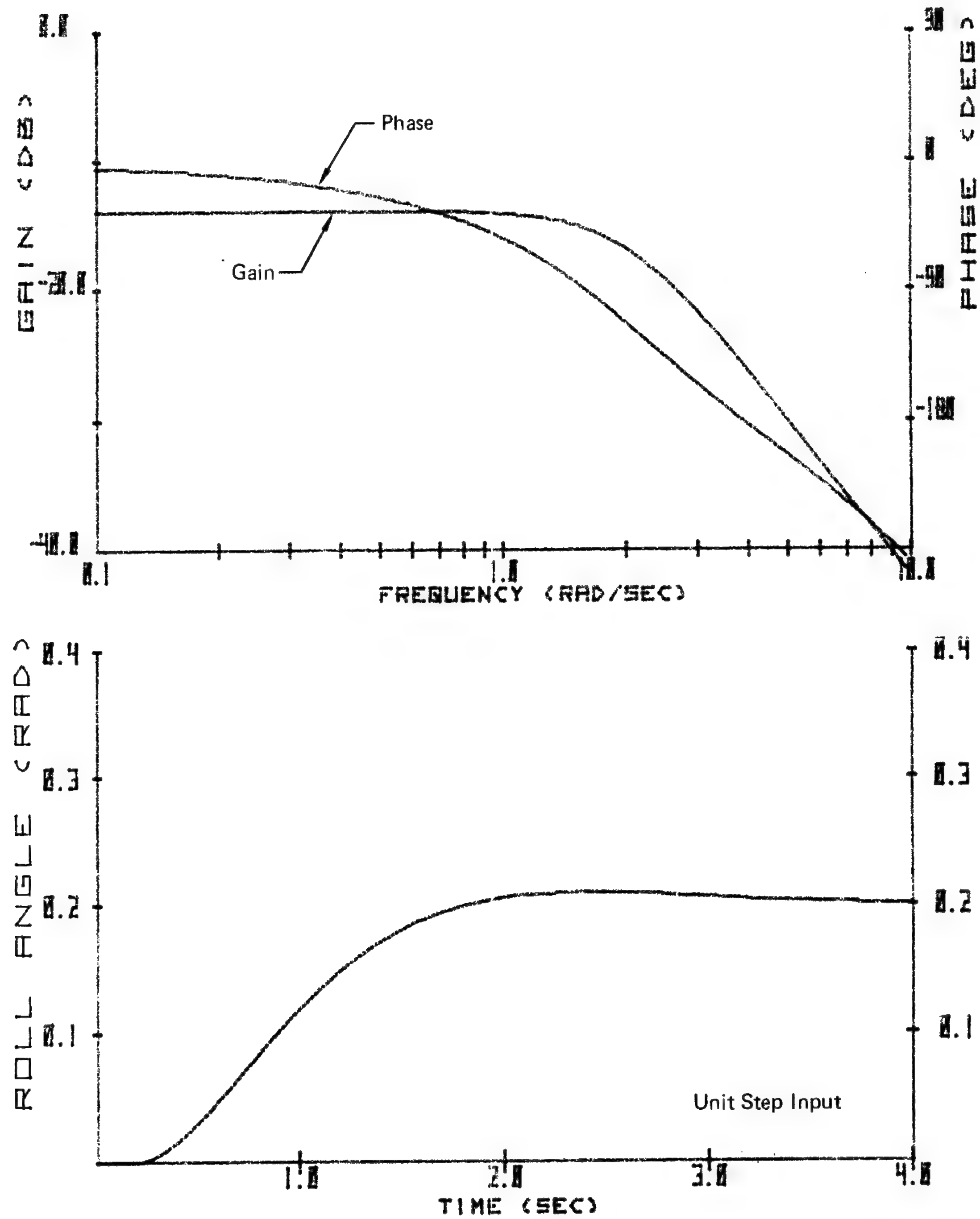


Figure A-54. Frequency and Time Response

Config G122
K = 0.2 τ = 0.2
PR: 6, 7, -, -



GP03-0208-89

Figure A-55. Frequency and Time Response

Config G180
K = 0.8 $\tau = 0$
PR: 3, –, –, –

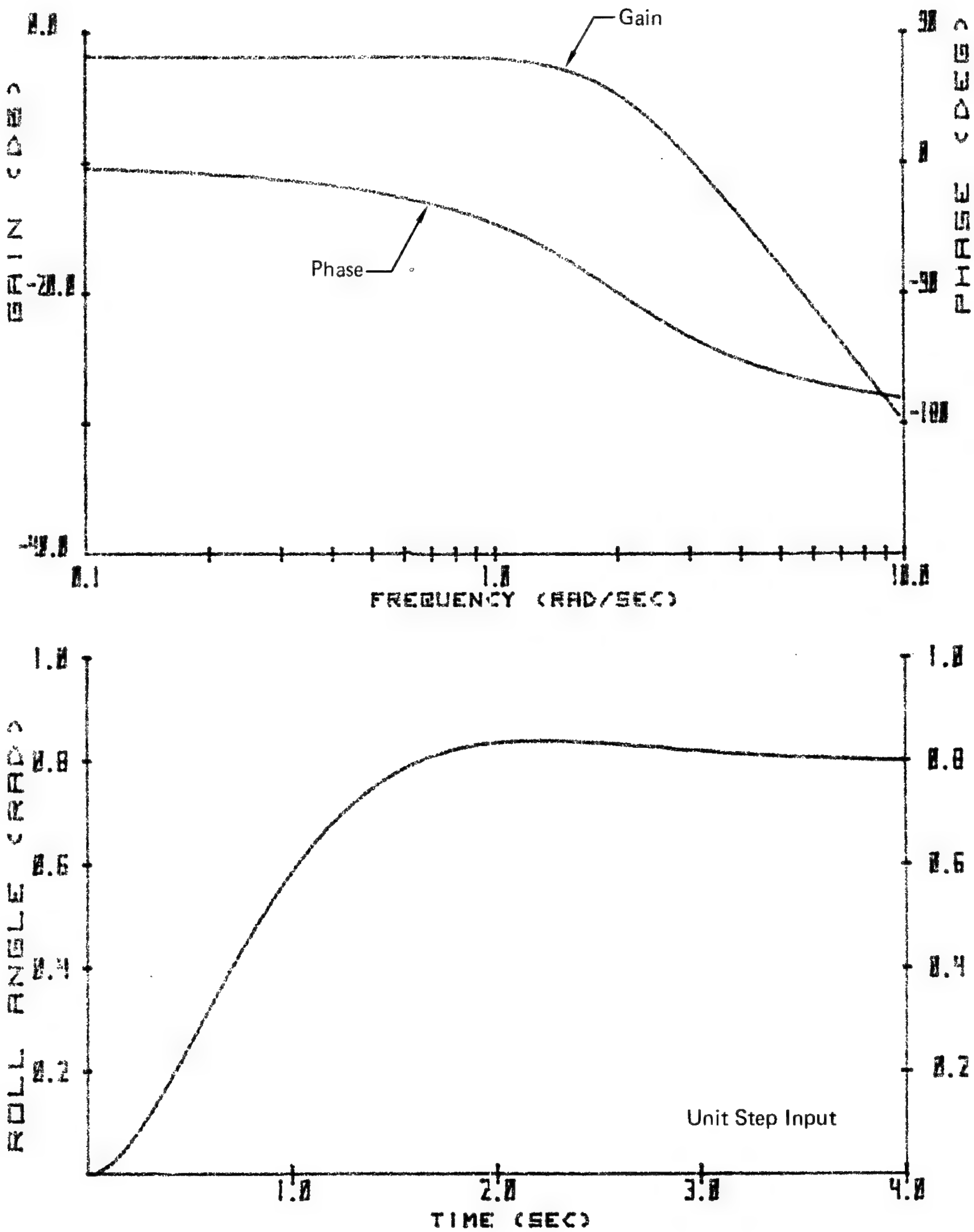


Figure A-56. Frequency and Time Response

Config G185
K = 0.8 τ = 0.05
PR: 4, -, -, -

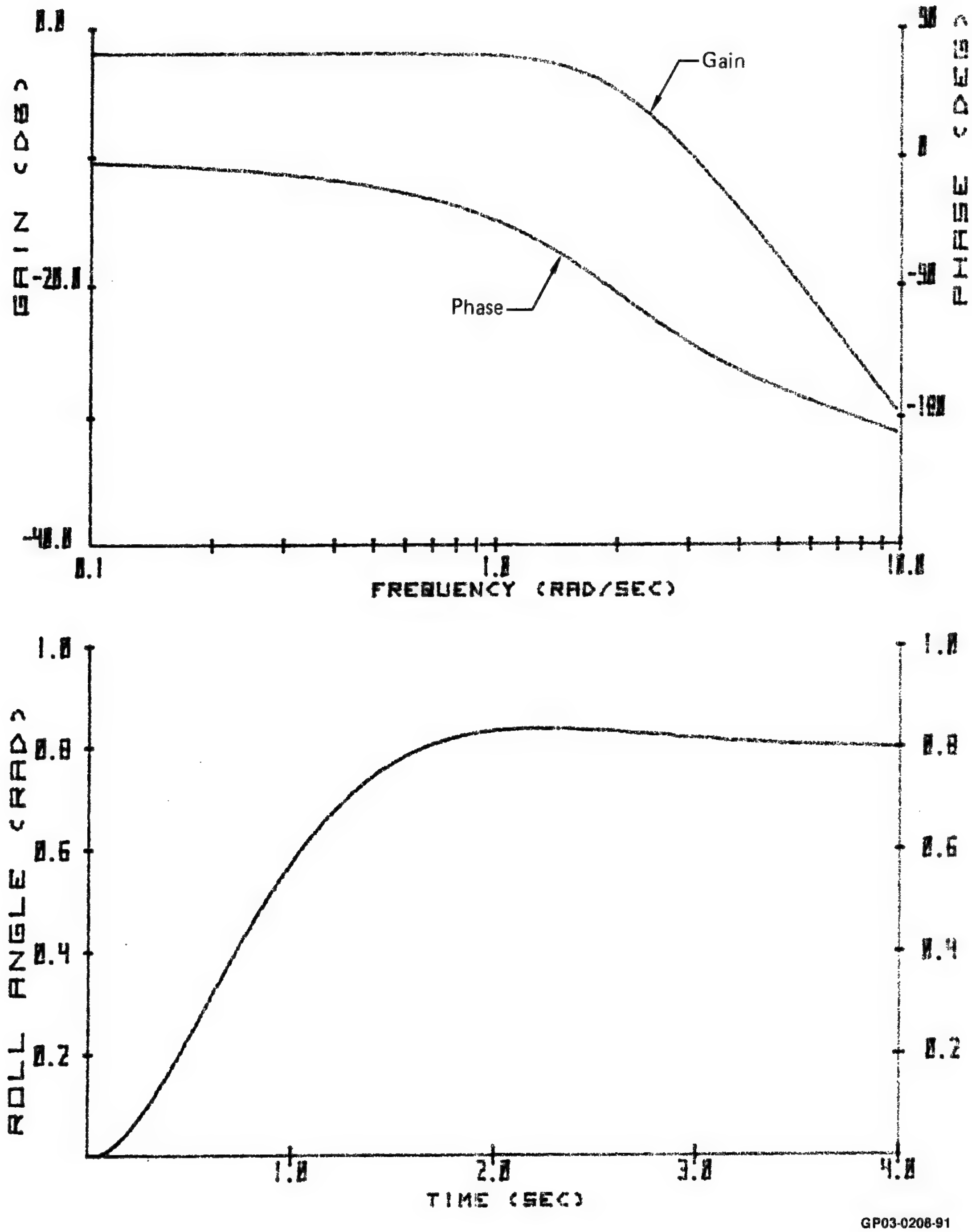


Figure A-57. Frequency and Time Response

Config G188
K = 0.8 τ = 0.08
PR: 2, -, -, 2

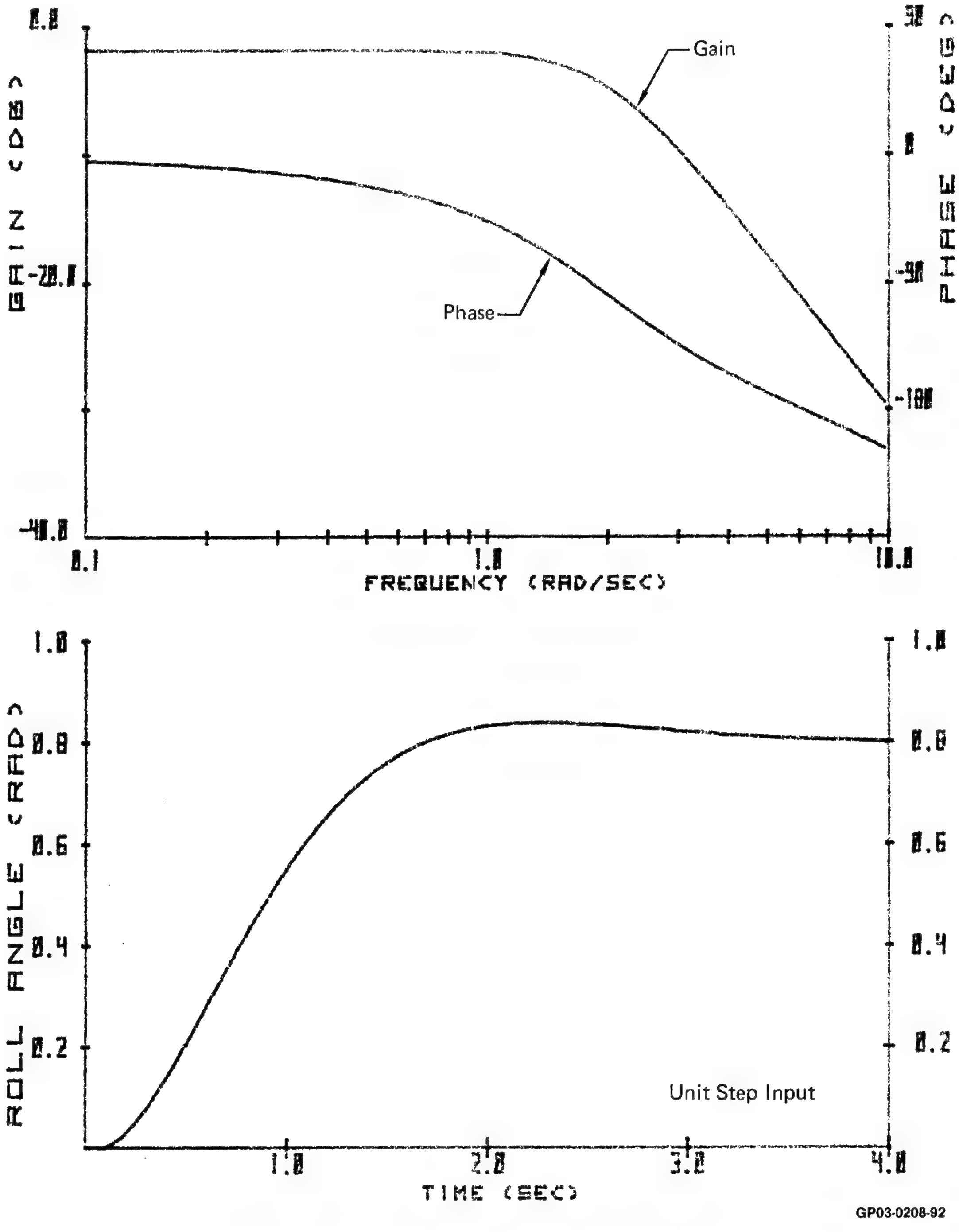
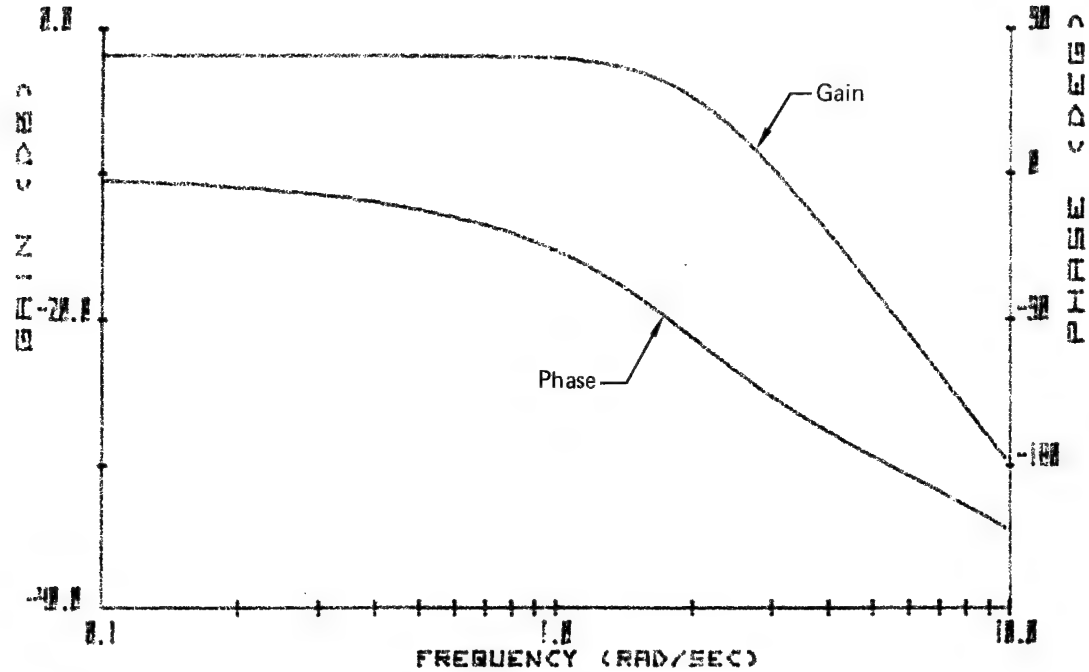
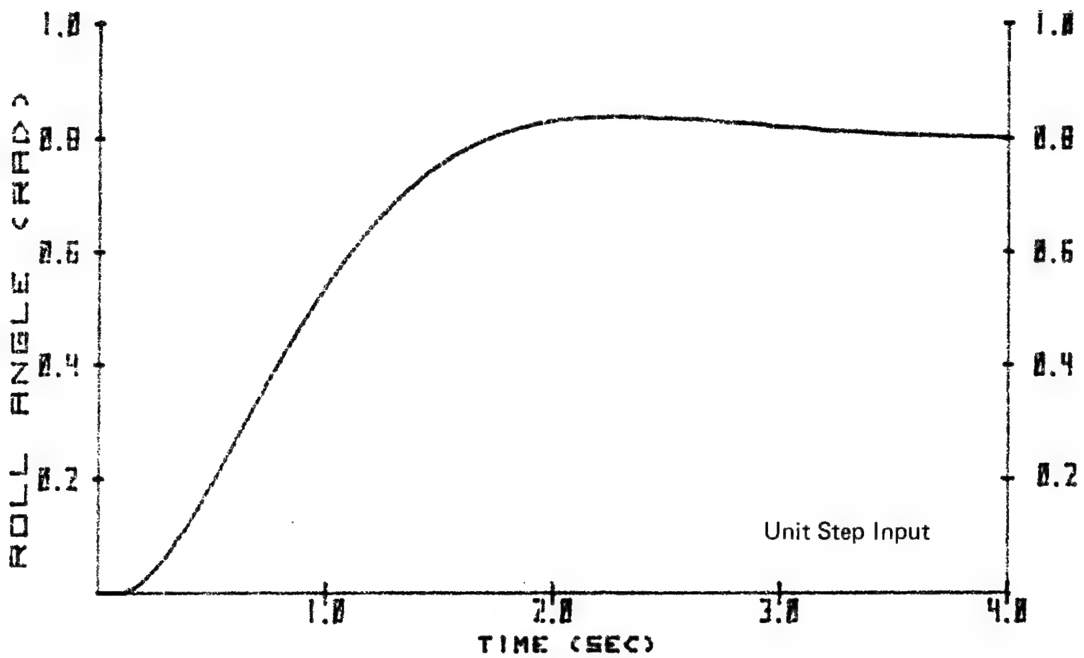


Figure A-58. Frequency and Time Response

Config G181
K = 0.8   τ = 0.1
PR: 5.5, -, -, -





GP03-0208-93

Figure A-59. Frequency and Time Response

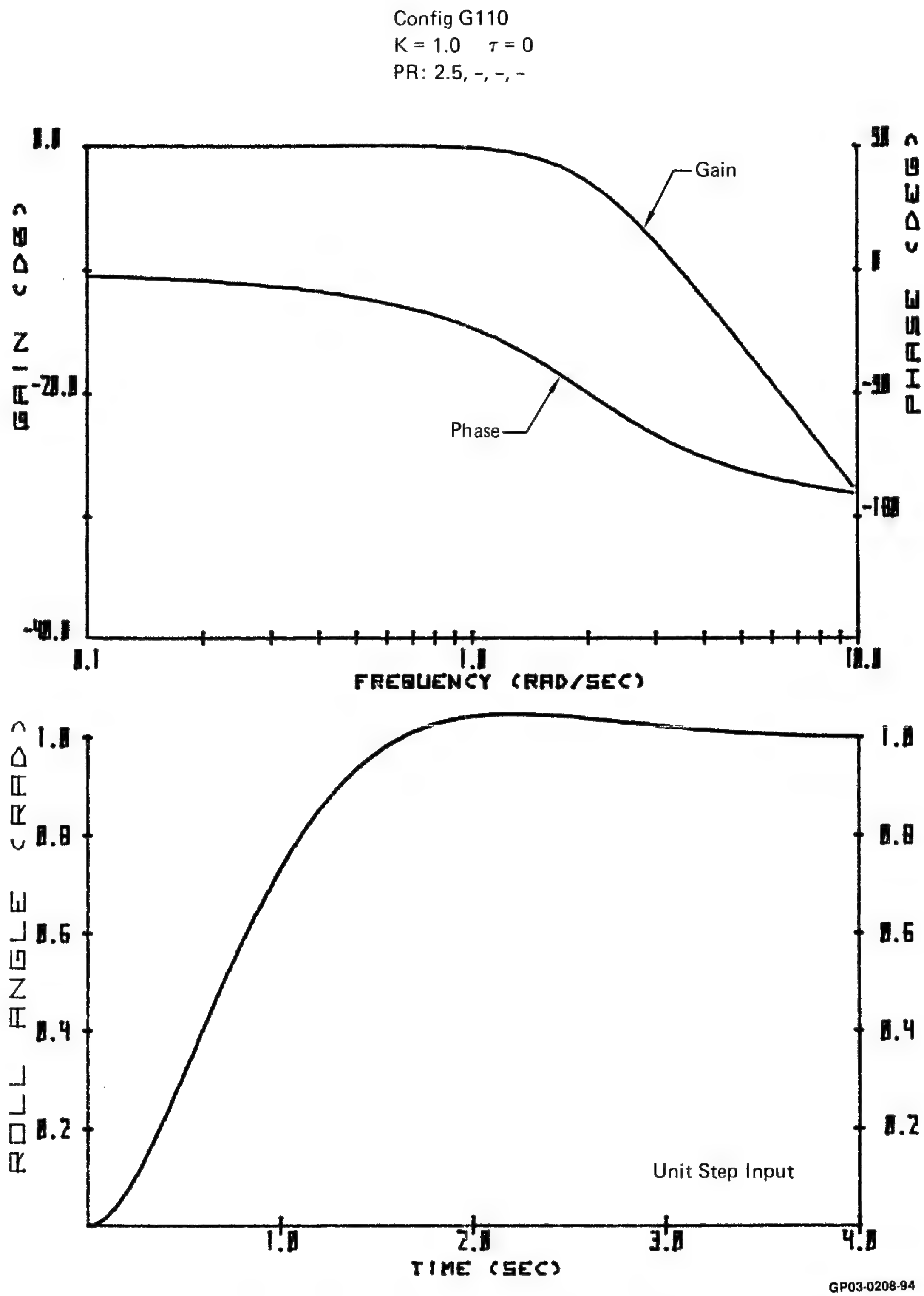
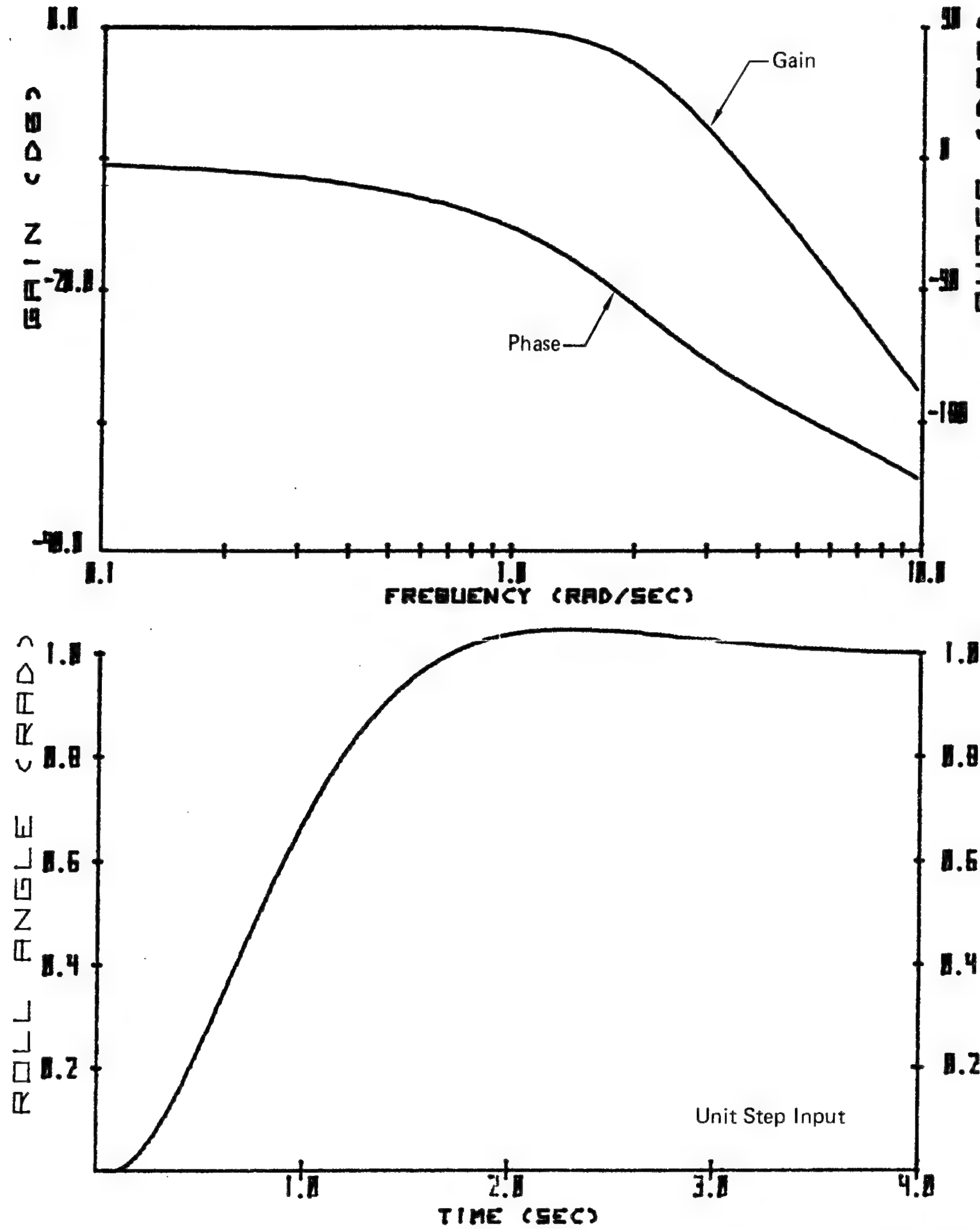


Figure A-60. Frequency and Time Response

Config G111
K = 1.0 τ = 0.1
PR: 6, -, -, -



GP03-0208-95

Figure A-61. Frequency and Time Response

Config G112
K = 1.0 τ = 0.2
PR: 7.8, 6, -, -

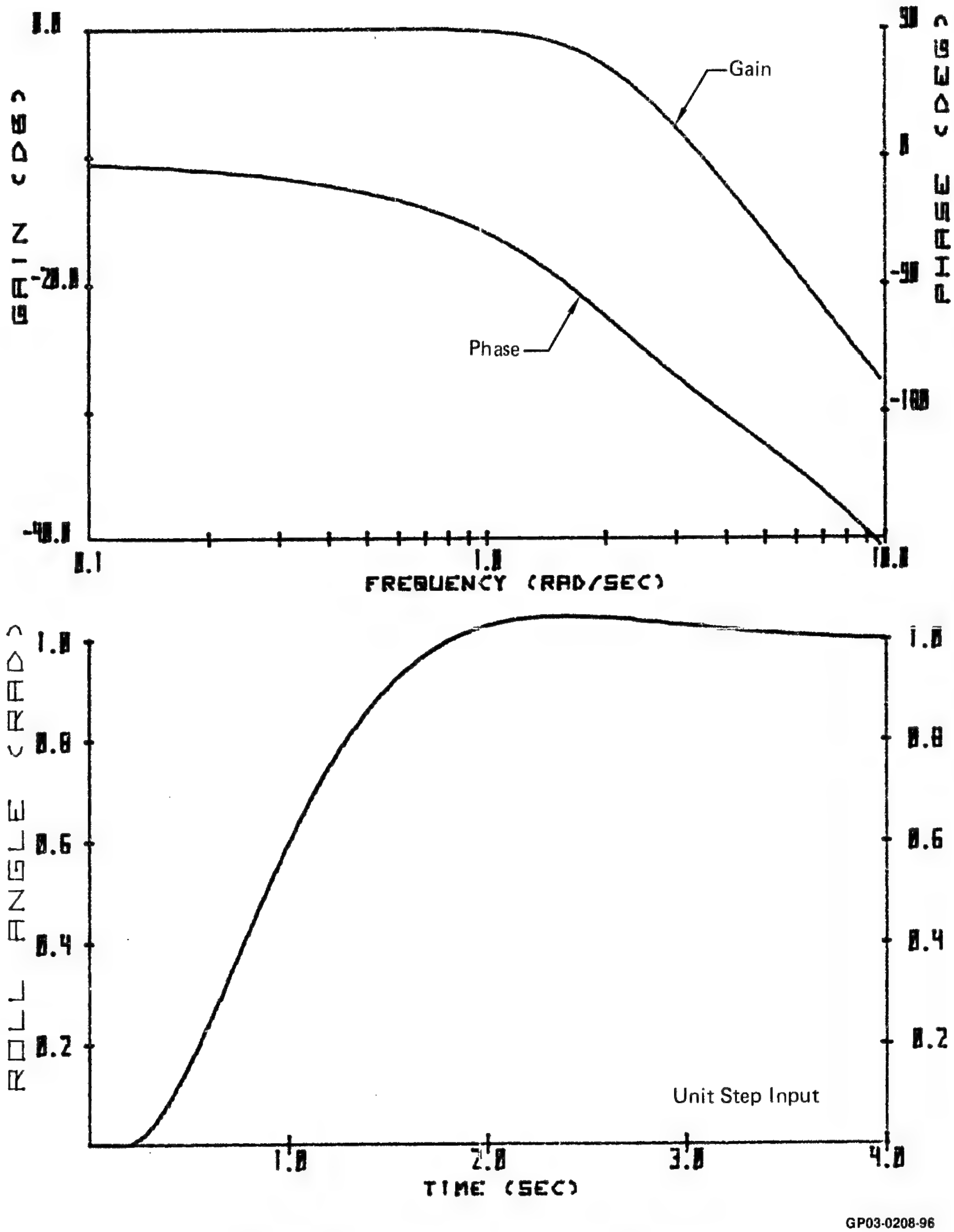


Figure A-62. Frequency and Time Response

Config G113
K = 1.0 τ = 0.3
PR: 7, 10, -, -

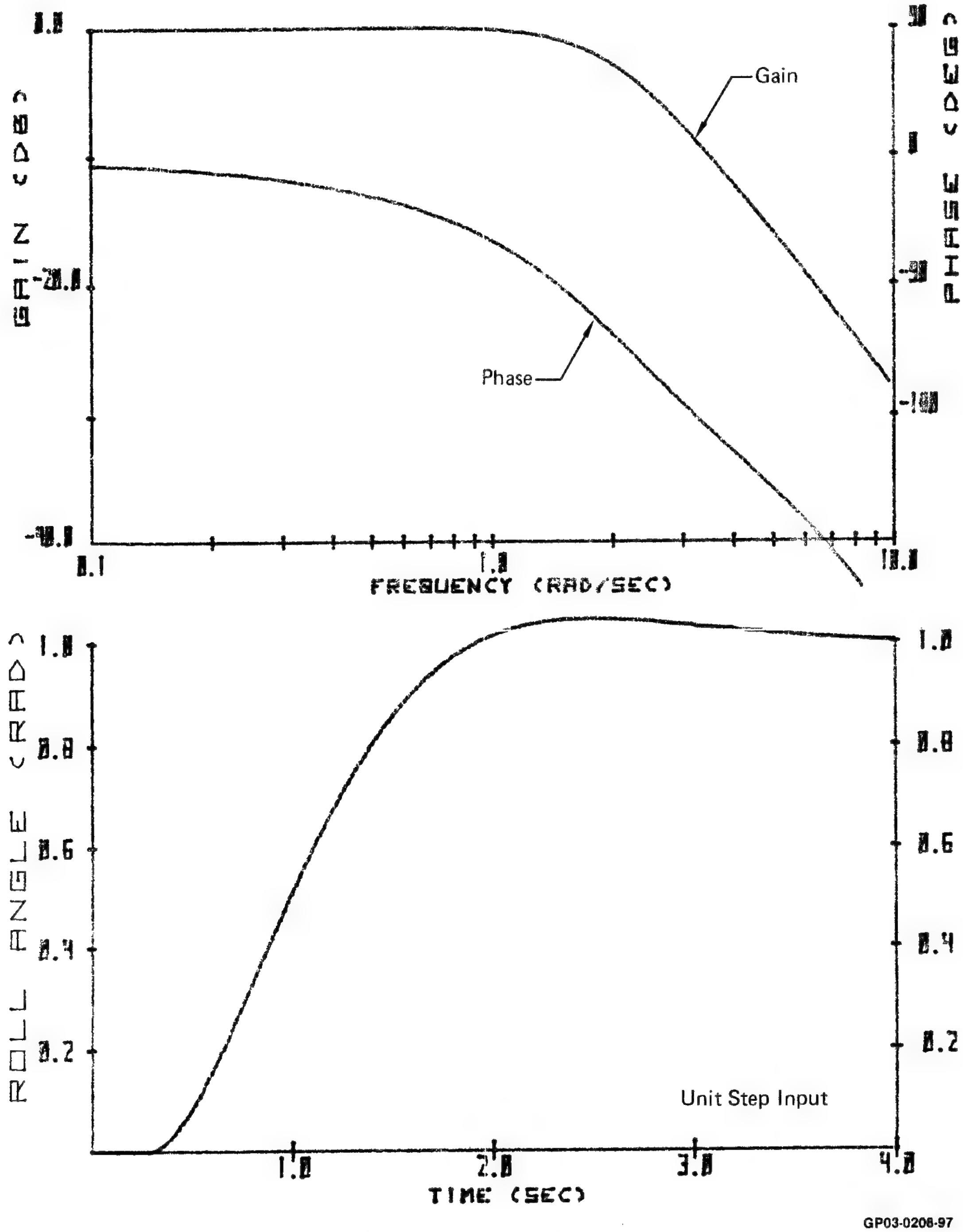


Figure A-63. Frequency and Time Response

APPENDIX B

Pilot comments presented in this Appendix are shown essentially verbatim. Only minor editorial changes have been made.

Pilot C's comments and ratings in a few instances are colored by his experience with a rate system. The attitude system appeared unfamiliar.

Pilot D had extensive experience with in-flight simulation, however time did not permit a lengthy familiarization with the ground-based equipment. This makes his ratings and certainly his comments particularly interesting, however, when his ratings differ substantially from the mean, this should be borne in mind.

Finally, it is evident from the comments that the side gust was very severe and tended to reduce the number of Level 1 ratings in the experiment. This bias was considered a worthwhile price to pay for the demanding task needed to expose flying qualities problems.

The configurations denoted with an asterisk (*) are the exaggerated "rooftop" systems.

N1LAT

Pilot D: 4 (K = .6)	The hover itself, once I did get settled down, I could stabilize reasonably well, so that as far as ratings are concerned, I think the airplane's clearly controllable. Is adequate performance attainable? I am a little bit doubtful about that.... I think that I could get the job done, but I wasn't really happy with it. My dominant feeling was that I was surprised at my inability to stop the airplane laterally where I wanted it.
Pilot B: 4.5 (K = .6)	It's quite sensitive laterally. It feels very similar to an AV-8A with the SAS on. It's no big problem. Forces very light.... you've got to compensate quite a bit laterally.
Pilot D: 7 (K = .6)	Initial response was okay.... I tended to over-control and there was a mild tendency to PIO in trying to be precise in coming to a hover laterally. The path response was initially okay.... I couldn't really get the job done to my satisfaction and I think it has major deficiencies. I don't really think that controllability was a problem.
Pilot D: 4 (K = .6)	General comments, I thought I could do a pretty reasonable job. It certainly was controllable. I thought I could get the job done whether it's satisfactory without improvement, I will hold out and say that I really still would like to be able to do the job a little bit more precisely than I could. So, I would say it's not satisfactory. I had just a slight tendency to not be able to do exactly what I wanted and when I wanted to do it with the bank angle. When I come to the end of the task getting hit with the gust and it takes awhile to get it settled down. Once I got it settled down, I could hold it reasonably precisely. I could fly the airplane precisely in attitude. The flight path response, I had problems stabilizing in the face of the gust in terms of holding a position. Once I fought my way through the gust, I could get back where I wanted. Again, I noted the attitude, perhaps I ideally would like less attitude for the velocities I've got. If I just had to sit there, out of the presence of gust and so on, the airplane would be satisfactory and a 3.

N1LAT

Pilot D: 3 (K = .3) The airplane is controllable. I could do the job. I had a little trouble contending with this wind gust and in some respects it's not maybe a fair task, but I do think the airplane was, I had a feeling of confidence about the airplane and I haven't had on some, I'd say it's satisfactory. I could get the job done. Mildly unpleasant characteristics. I could control the airplane very well out of the presence of the gust. I got the gust like on the left edge of the runway and I scooted right across to the right quite rapidly, more rapidly than I had before and I was able to bring the airplane to a stop within reasonable distance of the line with a fairly aggressive input... I really don't know how to judge my capability to contend with the lateral upsets. It's a fairly severe upset. The attitude response, it felt like a well tuned airplane in the sense that I felt like I could fly one to one with it, so it was okay in the attitude. Path response, I can't perfectly stop where I want, but I did as good a job as I've done all day here.

Pilot B: 3.5 (K = .3) The lateral is very comfortable. That's obviously a level deck command when I release it, it rolls wings level, no problem holding it in the bank angle and although I never tried full control, I found it very comfortable.

Pilot B: 5 (K = .3) I get the feeling that it just is not responding quite fast enough. There's enough of a lag that I'm bothered by them. I'm sitting there waiting, I need more response to it. I called for more bank angle and it seems to take a little bit longer than I think it should.

Pilot B: 3.5 (K = .6) I'm sure that the ride qualities might feel a little bit crisp, a little bit sharp when you roll it, but it certainly is a lot easier to handle and it follows, does more like what I'm looking for.

Pilot B: 3.5 (K = .45) It's a little less roll rate response than I would like to see, but at the same time, I found it very smooth and easy to control.

Pilot A: 4 (K = .45) I'd say it's a little bit sluggish taking off. Seems to be a little bit behind me. I don't know if the gains down or you got a delay in it. I'm not real wild about it.

<u>N1LAT</u>

Pilot A: 4 (K = .45) — Seemed to be slower to react as opposed to the previous one. It's not a gain difference, because I'm putting the stick over, I get plenty of bank and it takes a while to get in there. The build-up in bank angle is not rapid. It's not real rapid, so it takes time to get to the bank angle I'm commanding and I can't sort out if it's a lag combined with a slow system, or just a slow system. I can get chasing cause I can leave it in too long and then have to over correct when I take it out, so I've got to compensate for it. All told, it's not too bad. I would say that it's got an annoying deficiency certainly.

Pilot C: 7 (K = .45) — In the gust, it doesn't respond too awfully well. I got the opinion that I was pushing, I made an input, I started to get something and in response to that input and then it would die off and then I would have to make another input and then I would get a lot of it. Sort of a stair step if you will, it wasn't a smooth gradient. As far as a rating, it seems sensitive enough at first, but it wouldn't fall out. Gust response was very poor.

Pilot C: 6 (K = .45) — There's something that's a little perplexing to me on this one. At first, I thought I was lightly damped and then because when I was on the stick, I put something in and it would just continue to respond; however, when I got out of the loop a couple of times, it was fine.

Pilot A: 4 (K = .45) — What I'm seeing comes across to me as a lag in the response. That could be just a very slow rate build-up. It follows my commands going in pretty good. I notice it most when I try and take the command out and it takes awhile for the wings to get back level and therefore, I wind up overshooting and having to correct and come back. I don't know if it's lags or sluggish response or something like that, but it's coming across to me sort of sluggish, so I have to work harder than I think I should. It requires moderate compensation, I wouldn't say it's considerable. I might have some problems if I got down to a low altitude. It's something you just have to try and stay a little bit ahead of, so you do have to compensate for the airplane.

NlLAT

Pilot A: 4 (K = .45) Response seems down a little bit. I don't know if it's a matter of gain or rapidity. I guess I would like it either to be a little bit faster, or a little bit more sensitive as far as stick displacement. So, I usually wind up having to put in a correction and put in a little bit more than I originally put in. So, it takes me longer to damp out of oscillation. It takes me longer to get to where I want to go. I think it's something you could get used to, but it just comes across to me as being a little slow to answer the helm if you know what I mean. So, I guess I have to go back to saying that as far as I'm concerned, an annoying deficiency that I can't really put my finger on.

Pilot B: 4 (K = .45) Slight lag in trying to get back to neutral, but other than that, not bad at all.

Pilot B: 3.5 (K = .45) It would be a 3, if it was slightly more response. A little bit faster response, but other than that, it's nice and comfortable.

Pilot B: 3.5 (K = .45) Well, it's pretty good up until you start pushing out very far and then it stiffens up.

Pilot A: 3 (K = .45) I'm having some problems right around neutral. I just really can't find the neutral position. I don't know if it's weak centering, no breakout or what. I got to keep hunting to get that stick right in the center, so therefore, I'm constantly giving small lateral inputs and I think it's the feel system more than the dynamics. The airplane is going where I point it. I'm just having trouble feeling where the neutral point is on the stick and I sort of got to keep chasing the wing level position a little bit. Sensitivity is good, response is good and adequate, appropriate for the task. I have no problem making two axis corrections, I'm just having a little trouble in general finding the neutral point laterally. So, that gives me a small tendency for small oscillation in there that I don't think has anything to do with the dynamics. It's more having to do with the feel system. There is something in there that is annoying me. It's mildly unpleasant.

NlLAT

Pilot A: 3 (K = .45) I would say I like the sensitivity better. I could use a shade more response. I had no difficulty controlling the airplane. The airplane certainly goes where I point it. I have no major difficulty with the airplane and I don't think I would get into difficulty with it under any operation, so minimal pilot compensation is required.

Pilot A: 3 (K = .45) Interesting. Sensitivity as far as stick gain goes is good. Precision is good in so far as I see no oscillatory tendencies, no secondary response tendencies to roll back. There seems to be a little bit of lag in there. It is no more than a nuisance. I could get down fairly low there, so I did it intentionally on that second run. It's a minor annoyance category. I can make the airplane do almost exactly what I want it to do. It just takes a fraction of a second longer to get there than I think it should. So, it's got some mildly unpleasant deficiencies. I don't really have any major objections to the run.

Pilot A: 2 (K = .45) I'm satisfied with this one.

Pilot B: 3 (K = .45) I don't see any big problem with that. I found it very easy to do.

Pilot A: 3 (K = .45) The harmony and sensitivity is good. Perceived no large or unusual problems. I've got an altitude problem trying to split the difference when shown in discrete ten foot intervals, so it will be a little choppy on the altitude control.

Pilot A: 3 (K = .45) I guess I finally got this doped out. There's no problem with the lateral controllability in isolation. However, compared to the longitudinal sensitivity, it seems to me that lateral sensitivity is down just a shade, therefore, there is a minor harmony problem. I think if you made a longitudinal adjustment here, I'd have to give it a Cooper-Harper 2. As it is, I'd say the harmonization bothers me just a little bit.

N1LAT

Pilot A: 3 (K = .45)	No problems at all. Sensivity is good; no delays.
Pilot A: 3 (K = .45)	I don't perceive any additional mode in the mid-frequency range. It's predictible. Sensitivity is pretty good. I might wish I had just a shade more response; however, I've got no gripes at all about the configuration.
Pilot A: 4 (K = .45)	On the first run, I seemed to get almost in a continual ±20° of bank oscillation. However, the two subsequent runs, I can't really perceive any real problem with it. The airplane is slightly sluggish and it may be caused by a bit of a delay; however, sensitivity is good and appropriate to the task. I guess as long as I fly the airplane properly, I can make it do pretty much what I want to do with it. I guess I wish I was just a little bit more rapid in response. I can make it go where I want it to with moderate pilot compensation.
Pilot A: 3 (K = .45)	I like that configuration. Sensitivity is good. Predictibility is excellent. The only problem is I guess I wish the onset rate was a little faster. In other words, it comes across just slightly on the sluggish side. However, you can certainly make exactly what you want. I'd be tempted to give it a 2, except for the comment on sluggishness.
Pilot A: 3 (K = .45)	The airplane does what I want it to. What more can I say.
Pilot A: 3 (K = .45)	The only problem with the configuration at all is it is just a shade slow on the response. Not bad at all. Definitely Level 1, the choice should be between a Cooper-Harper 2 and Cooper-Harper 3, but since I think I would like the response to come on just a little bit faster, I would say I am compensating for it so, therefore, I've got to put some small compensation in it.
Pilot A: 2 (K = .45)	We're back up to a Level 1 airplane. I can't really put my finger on anything that I would change. It's got very good flight characteristics, good sensitivity, good response, negligible deficiencies.

N1LAT

Pilot A: 2 (K = .45)	It seems like a very nice system. Sensitivity is good. Control harmony is good. Control force is good. Response is good. No noticeable lags. No sluggishness. It's a very pleasant system to fly.
Pilot A: 5 (K = .45) $Y_V = -.2$	No controllability problems. The problem with it is, the rate of onset is a little bit slow and therefore, it takes a long time to get a correction in, which means that by the time you sense that you need it and put it in and the airplane reacts, you need more and you can't station and keep exactly to that shear, so I can't get the desired performance. It's certainly adequate.
Pilot A: 4 (K = .45) $Y_V = -.2$	That's almost Level 1. The problem is that the onset rate is just a little down, so the airplane comes across as being a shade more sluggish that you would really like. It might be real decent in flight, considering the ride quality, so a flight article might be better. As far as the simulation goes and the ability to make small corrections, I have to work harder than I think I should.

HF111

Pilot A: 7 (K = .45) $Y_v = -.2$	Response is way down. It's certainly adequate for a DC-10 or B-52 (large aircraft). It's inadequate and inappropriate in a fighter sized airplane. So, I cannot get desired performance, I cannot get adequate performance, so I'll have to say that adequate performance is not obtainable with maximum tolerable pilot compensation, it's just not there. I've got no question about the control, controllability of the platform. You don't have enough to get in trouble with.
Pilot A: 9 (K = .45) $Y_v = -.2$	The airplane is just too sluggish, plus the response is down. Controllability is very definitely in question. I was in a continual bank to bank oscillation that I could not get out of. It was just like being on the end of a pendulum. There's no way I could have landed that machine. I question that I ever really had adequate control of it in the first place.
Pilot A: 7 (K = .45) $Y_v = -.2$	The airplane is just too sluggish. Definitely a Level 3. I can't even get adequate performance. It just takes too long to get anything done and I do have some qualms about control. With a differently defined task, there may be a controllability problem in that you could develop a large bank angle in close to the ground for instance, and just not be able to get it out in time. So, for the way we've got the task set up, and for what we're doing here, I'd have to say you're not bordering on loss of control. In a close confines environment or things like that, I think things could get pretty hairy in a hurry.
Pilot A: 7 (K = .45)	The problem here is a very, very sluggish response. Again, absolutely no question of being able to make small corrections. They're just not there. The question is again, can I even get adequate performance out of the configuration, added to a slight hedge on possible controllability. I'm getting into that factor being able to generate a fairly large bank angle and not be able to get rid of it in time, so I'm still back in that 6, 7, 8 ballpark. I don't think I can get what I would consider adequate performance out of the machine. It just isn't there. I wasn't really having a controllability problem, although I was oscillating from one side of the runway to the other and from $\pm 20/30°$ of Mag. For this task controllability wasn't a question. If you got a precision low altitude task, it might be.

HF112

Pilot A: 8 (K = .45) $Y_v = -.2$ — The airplane is too sluggish. With a low response, there's not much of a question of controllability, because you don't have enough to get into trouble. What we have is the rate is too low. In that case, you can get into trouble because you can generate a very large bank angle and not be able to get it out in a hurry, which means that you're all the way over to the other side. You couple that with a little bit of lag in response and you've got a disaster. I think the pilot does have to stay on top of it in order to retain control and there's not even a question of being able to do any station keeping within a configuration.

Pilot A: 6 (K = .45) $Y_v = -.2$ — Well now, response is very, very, very sluggish. It's like flying a heavy. It might be typical of what you could get into with some total configurations, however, compared to what we've been seeing as typical in this simulation, that is a very sluggish response. I found myself in almost continual bank to bank oscillation of about 20°. I never got real close to the ground, but I suspect in a close to the ground situation, with something upsetting you initially, it might be a little bit of a wild ride in there. I guess I'll say as far as I'm concerned, it's a very objectionable deficiency in that the sluggishness, I can get adequate performance, but because of the slowness, I certainly can't get the desired performance.

Pilot A: 6 (K = .45) $Y_v = -.2$ — It might be an interesting configuration with a little bit more time delay in it. As it is, the airplane is just too sluggish. It's got very high sensitivity combined with a sluggish airframe. You got plenty of bank angle, it just takes a hell of a long time to get it. What that means is there is no such thing as a small correction, because by the time you get the bank into a small correction, you need a bigger one and by the time you get that in, you know a large one, so it's a process of continual fairly large amplitude corrections and the airplane is always way behind. I can't get the desired performance. I can barely get adequate performance. There is no question about control at all. I am getting adequate performance.

Pilot A: 5 (K = .45) — Moderately sluggish response, maybe some lag in there. Again, I can't make the small corrections I would prefer to make, but I can get the corrections in, in a decent amount of time. I'm getting adequate performance.

HF113

Pilot A: 4 (K = .45) Y_V = -.2	I'm not quite sure what you got in this configuration on that lateral control. It feels a little bit loose, almost like there is a couple rates involved in the bank angle onset. I can control it and I don't have any real problem with the lag. It seems to follow the stick fairly precisely. I guess I wish I had a little bit more response to small inputs, but I don't have the problems of a constant bank to bank oscillation. I feel I can get the job done. It's got some annoying deficiencies.
Pilot A: 3 (K = .45) Y_V = -.2	In the process of keeping good altitude control on these runs, I was very smooth and cautious on my input, so I don't want any of the cosine effect on bank angle. Therefore, I can't really give you a good evaluation on large scale maneuvers, I didn't make any. The airplane responded well to what I was asking it to do. I was getting pretty much what I asked for.
Pilot A: 5 (K = .45) Y_V = -.2	It's an almost good configuration. The problem here is the airplane is sluggish. It's predictable, it just takes a little bit too long to get in there and if you happen to make a mistake, it takes a long time to correct for it, because you have to go the other way and the airplane has to build-up rate and everything, so the sensitivity seems good. I don't notice any particular lags in it, although response is just slow, so I guess I'll say it's a moderately objectionable deficiency.
Pilot A: 6 (K = .45) Y_V = -.2	The airplane is just too sluggish. You know what happens when you need a correction as it takes a long time to build. Therefore, you need a bigger correction and you get it in, you get everything stopped - then you've got to take it out and by the time you take it out, you're going the other way. So, you've got to over correct and you get into an oscillation, a real nuisance. A major problem with it. However, I can get the adequate performance. I'm just not real wild about it. Very objectionable, but tolerable deficiencies.

HF113

Pilot A: 6 (K = .45)	Very sluggish. I don't know if it's sensitivity, change in the lag or whatever. Although the configuration is sluggish, I can get corrections in more rapidly. I do have a tendency to get a constant sustained low amplitude wing walk, but I can stop the drift and I can get reasonable performance. There's no question of being able to make small corrections. It's just not there. But I think I can get reasonably adequate performance. I can stop the drift in other words. I'll say it's got the very objectionable, but probable deficiencies.

HF114

Pilot B: 4 (K = .6)

A little bit light laterally, other than that I'm compensating only slightly.

Pilot A: 5 (K = .45)

That was interesting. When I first saw it, I was about to say it was a pretty pleasant configuration and I got into a pretty wild lateral overshoot. It's pleasant and I think the harmony seems good, I'm getting about the response I think I should be out of the stick. I don't know if there's lag, or it's sluggish or what. I got behind it in a hurry on a couple of occasions it seems like, so it's a little puzzling. The dynamics seem quite good. It's dead-beat. I put stick over, it answers with about the response I think it should. I guess it just takes awhile getting there. Without the wind, I'd have probably said that was a very good configuration, but when the wind hit me, it took me awhile to damp it out. Puzzling. So, I can't get to the desired performance. I can certainly get an adequate performance, the difference is that I can't make it do exactly what I want to but, I can almost get there.

Pilot A: 6 (K = .45)

I'm trying to decide if adequate performance is or is not obtainable. It's coming across to me as sluggish. I don't know if it's just flat sluggish or if there's sluggish plus a delay or just a delay. I'm considerably ahead of the airplane which means that I can't get into this overdrive situation. Got some oscillations in there, which I don't think qualifies as PIO because I could back out of it so easy. I don't like the configuration. It is very imprecise. It's certainly moderately objectionable. I can't get the desired performance. I'm in the adequate performance category.

HF115

Pilot B: 3.5 (K = .3)	I don't see any big difference from the last three runs.
Pilot C: 6 (K = .45)	Continual small PIO problems with that one. It is very nice really except in one place and that's when the pilot is in the loop for small corrections and then the airplane, the wings just sit there and oscillate up and down and then you take your hand off the stick and they quit.
Pilot A: 5 (K = .45)	It seems like there are several things wrong. There's just a bit of lag. There seems to be some kind of oscillatory or second stage response in there. It comes across as being unpredictable. I never quite get what I think I'm going to get out of the stick and it takes awhile to get it all, and as a consequence, I'm making larger corrections than I really feel are necessary, and more of them. So, as a consequence, I can't get what I would consider to be the desired performance. I can get adequate performance certainly and it doesn't require an awful lot of effort to get that. It's a quirk, it's a nuisance, it's not predictible. It's moderately objectionable.
Pilot A: 4 (K = .45) Y_v = -.2	I seem to have lost some mid to higher frequency performance. It's ignoring small inputs. I'm having a little bit more trouble getting small corrections in, because it tends to ignore some of them. I can get the job done and it's a nuisance more than anything else. It's not a question of extensive pilot compensation, yet it's an annoyance.

HF116

Pilot D: 5 (K = .6)

In general, the airplane was controllable. I think you could get the job done. I was partly influenced by my last wandering around and trying to settle down on the position on the last evaluation. I don't think it's satisfactory. I think it's a smooth airplane. There's a tendency to not be able to learn how to precisely predict where I'm gonna stop over the ground and I felt like I tended to not have the right match between bank angle and the resulting translation that I wanted. In any event, there is not serious problems compared to some of it I've seen, but it is not satisfactory, but I think that we're talking about achieving adequate performance as opposed to desirable performance, but I could eventually salvage something here. When I'm stabilized in the hover, although in the face of these gusts, the wind shears I did have some difficulty at the end. Attitude response seemed smooth and predictable to me. I felt comfortable. I cannot really solve the problem of how to smoothly stop. That's why I gave it the unsatisfactory rating. No tendency to really PIO. I was able to in the face of the wind shear, which just about the time I'd get enough bank angle in to correct for what is a fairly large wind and stop from moving to the left, and move back to the right then it disappears and I end up over controlling and translating too far to the right, but despite that, I was able to recover from fairly large bank angles quickly and with reasonable predictability. The flight path response, I said in the face of the gust from the last one in particular, I was moving around more than I wanted to. Somehow I think that I would like to use less attitude to get translation. The wind affect seemed rather severe. Turbulence, I can't say that I really noticed anything.

Pilot B: 4.5 (K = .45)

There's enough lag in there that it bothers me a little bit. It's not hard to use or anything of that sort, and it's nice and smooth and tends to follow the stick pretty well, but at the same time, there's some sort of lag there that I can't sort out, but I don't like it very much.

HF116

Pilot A: 5 (K = .45)	I'm seeing a perceptible lag in the response. The underlying dynamics are good. They're pleasant. Rate build-up is good. It's predictable. You got to stay ahead of the airplane and plan what your gonna do in advance more or less and not try and make any rapid corrections. As long as you keep your bandwidth down, it's not a particular problem. If you got into a real high gain situation, close to the ground, I think you'd have problems controlling it. I don't like the lag in the response. I think that I'd get in trouble with it, so I've got to give it considerable pilot compensation by staying ahead of it.

HF117

Pilot B: 4.5 (K = .3)	That's a lot better. I can make smoother inputs. I'm still getting some of that bang, bang effect, but I find it to follow what I'm asking it to do much, much better.

HF124

Pilot B: 6 (K = .6) As far as the overall airplane is concerned, nothing really different except the lateral system. The lateral damping is obviously considerably reduced. Adequate performance requires extensive pilot compensation and that's true laterally, the thing oscillates unless I really determine that I can get it into the center and stop the lateral oscillation. It's not in the 7 category because I can attain adequate performance. It's objectionable to tolerable.

Pilot B: 7.5 (K = .45) The lags are too high and it's totally uncomfortable.

Pilot A: 6 (K = .45) I think I could get myself in a dangerous PIO in a high gain situation. As it was, I never really got out of the loop. I was in a small amplitude PIO throughout the whole thing. The lags noticeable and objectionable. I certainly can't get desired performance and I'm not totally sure I want to call it adequate. It's a reasonable probability in a slight higher gain task I might want to go worse than that.

HF125

Pilot D: 7.5 (K = .6) Controllable, yes, it's controllable. I can't do the job, I get into a fast high frequency over control PIO type situation anytime I try to be precise with the airplane, so it has major deficiencies. The attitude response was initially quick, but it was not predictable. I could not stop from seemingly putting inadvertent input. Special techniques would be to try and keep yourself consciously from being too active on the controls. There was a tendency to PIO. The path response was bothered because I got preoccupied with trying to stabilize the airplane in attitude, so the predictability suffers there. When I did get it translating it seemed to be the attitudes were reasonable for the translational velocities I was getting. The lateral disturbance wind shear or whatever it is, really upsets the apple cart with this thing, because you get it almost stabilized and then you get this task to compensate for the wind and several times, I ended up translating back and forth and that's very uncomfortable to fly because the motions are very rapid in the simulator and I find my eye balls getting a little bit crossed with whatever is going on the display with the very rapid movement.

Pilot B: 6 (K = .3) I move the stick and then there is a delay. Nah, that's no good. You've got to have positive response right away. This thing isn't stopping when the stick moves. Good Lord, it's half a second or so. Maybe even a second, yeah it's closer to a second delay in there. It's not all that hard to do, because it's basically flying itself, but the lag is what's getting to me and I could get myself disoriented very easily if I didn't have really good cues. I'm compensating for that lag by saying okay, I'm gonna have to move it now, because a second from now I'm gonna see something happen or 1/2 second to a second someplace in there.

Pilot A: 5 (K = .45) $Y_V = -.2$ The problem here comes across as a transport lag. The thing to consider is a modest amount of time before the airplane responds. Therefore, I've lost the ability to make small corrections. Therefore, I can't get the desired performance. Now, adequate performance, yeah, I can certainly obtain that. The difference being I just can't make small corrections. The question of compensation is almost removed. Nothing you can do about it. The vehicle just doesn't have it with that much lag, so in order to get what I consider adequate performance takes some amount of work load, there's nothing I can do by increasing my own work load, my own compensation, to improve the performance of the vehicle.

HF126

Pilot B: 4 (K = .45)	I kind of like it in a lot of ways. I can't quite nail it down as tight as I might like to, or as tight as some of those others, but in the absolute hover it's much more comfortable in maneuvering areas.
Pilot A: 6 (K = .45)	It does have a noticeable lag. That one comes across as having a noticeable lag in the response. Underlying dynamics almost seem like there is something else in there. My major objection is it takes awhile to get anything out of the aircraft and therefore, by the time I sense the motion starting and put a correction in and the airplane reacts, I've got an over correct. I put in more, a rate, lateral rate, has built-up, then the same thing goes taking it out. I get a little bit behind, so I get into this lateral oscillation, not only in bank, but actual lateral position, so it was sliding back and forth, so that one's got objectionable deficiencies. I certainly can't get the desired performance. If I really back away from the task, I wouldn't have any PIO type problems. I've got to do two things, one, I've got to continually over-correct, and two, I've got to simultaneously back down on my expectations, so I'm gonna have to say that I can get adequate performance with considerable compensation.
Pilot B: 4 (K = .45)	A little longer lag here. It's really not much different than the last one other than the slight change change in lag.
Pilot A: 5 (K = .45)	I can sit there and oscillate the stick back and forth as much as is comfortable, like say two inches either side of center, at what I don't consider to be an unreasonable frequency and get absolutely no lateral response. I've got good prompt performance. The steady state gain is good. I've got all the control out there that I want. It takes awhile to get there, but it totally ignores small corrections, so I've got all the gain I could possibly ask for as far as getting this thing stood up on its wing tip, but I have lots of trouble making small corrections and it just doesn't respond to small inputs. So, I can get adequate, I can't get the desired performance, cause I can't make small corrections I want to, I can get get adequate performance and it's really not too hard.

HF127

Pilot B: 5.5 (K = .3)

I'm flying all of these in more of a bang, bang fashion than the smooth control input that I'd like to be able to make. I'm just chopping in there with the stick waiting for something to happen and then banging it back out waiting for it to happen, rather than smoothly flying it. I might just as well have a button here and press it for left/right and release it for back to wings level. It's just I don't care for this at all. I don't like the way you have to fly the airplane in order to get done what you need to do. It needs to be a smoother, more continuous effect, rather than this bang, bang effect which is what I find myself doing and I don't like that.

Pilot A: 7 (K = .45)

You got a perceptible lag in the system. Underlying dynamics are good. Rate build-up is okay. The gains okay as far as bank angle per stick deflection or such like things. The lag creates a problem in that you start over-correcting. You put in what you think you should and it's a little late then you need more in and you put that in, then you gotta get it out, so I think you could get into pretty much of a sustained PIO, in a high gain task. I think close to the ground, that would definitely be Level 3. For the task I'm doing up here, I can tolerate the workload, but I can't really get what I consider to be adequate performance.

Pilot A: 6 (K = .45)

If I ever got into a high gain situation, I would follow the couple right into a PIO. It's very objectionable. At this altitude it's tolerable. I think in close proximity to the ground, there would be a major problem with that.

HF128

Pilot A: 4 (K = .45)

Well let's see what we've got here. We got a small lag in the response it seems like, combined with a rather soft dynamics. The overall impression is the airplane is just a shade sluggish. However, the lags and the slow rate sort of blend together naturally, so there is not a controllability problem. It just takes a while getting what you want out of the airplane. So, you can make it do what you want it to do, maybe not quite as rapidly as you would like. I had no problem making the airplane respond to what I think I want out of it. So, although I wish it happened a little bit quicker, I'll say that I can get the desired performance.

Pilot A: 5 (K = .45)

You got a moderately slow responding airframe, coupled with some lag. However, the lag seems to be appropriate to the airframe dynamics and sort of hard to settle it out. It just comes across a little sluggish. Sensitivity is pretty good compared to the previous configuration. I like the sensitivity fairly well on that run. The problem is, I cannot make rapid corrections. The airplane just does not get it on, so therefore, I lose a bit of precision. I can certainly get adequate performance. I can't get what I would really like the airplane to do.

HF129

Pilot A: 3 (K = .45) — I don't know, sometimes I think I'm seeing a mid-frequency superimposed response in there. You know, like just a little oscillation in the mid-frequency range and sometimes I don't see it. Whatever, it's no more than a minor nuisance. I can certainly make the airplane go where I want to. I don't have any harmony sensitivity or lag problems.

Pilot A: 4 (K = .45) — I guess I would say that that's almost a good configuration. Sensitivity is good. Response rate is fairly good. It could be just a shade faster, but I guess I'm seeing a little bit of lag in the response that makes it a trifle less than optimum in predictibility. If given a couple seconds, it goes where I want it to. I have minimum difficulty controlling it, but there is a quirk in there that I'm having some problem with. I will say it's a minor, but annoying deficiency.

Pilot A: 4 (K = .45) — I'm not quite sure what we've got here. It comes across to me as predictibility as being down a little bit. I don't know if it's an additional mode or a bit of a lag or oversensitivity or a combination of all things. I'm just having a little bit of problem guessing where the thing is going to or adapting myself to how much response I'm going to get, so it comes across as being less predictible than I would like. I have to provide more compensation in the form of having to make two or three corrections in order to get the job done than I would like. I can get the desired performance, I just got to work harder for it.

Pilot A: 4 (K = .45) $Y_v = -.2$ — Dynamics pretty good on that one. Sensitivity may be just a little bit low. I want to hedge that, not necessarily sensitivity, the rate might be just a little bit low. In other words, from the time I perceive a correction until the airplane gets it in, is a little bit longer than I would really like. I can certainly do the job. I put it in the minor but annoying deficiencies category.

HF120

Pilot A: 5 (K = .45)

There may be some lag in the response. It sort of ignores small rapid inputs. As a consequence, the response that I perceive is always stepy. I either get too much or not enough. Moderate size inputs, it almost seems like there's another mode in there that I'm not controlling, that's just sitting there bouncing around. I can make the airplane go more or less where I want to, but I find my inputs being step inputs, I'm going bang, bang on the control, I'm getting a very rapid step like response and I'm not real wild about it. I think it would be uncomfortable in a real airplane. It's definitely not the way I prefer to fly the airplane, so I'd say that deficiency certainly warrant improvement. There are at least moderately objectionable deficiencies. It's not so much a matter of extensive pilot compensation, as it involves a different mode of flying than I would really prefer to use. It does force me into a different mode of operations. I'll have to say it's a considerable pilot compensation.

Pilot A: 5 (K = .45)

We've got a moderate size lag in this configuration, combined with a moderately sluggish response, it means that the pilot has to sort of stay on top of things. You never have serious doubts about your ability to control it. You just wish that you could get what you wanted a little bit quicker. Desired performance is not obtainable, because there's a lag in there, but adequate performance certainly is.

Pilot A: 3 (K = .45)

No real qualms with that. I think there might be a minor lag in there, but the airplane does pretty much what I want it to. I guess there's something in there that's bothering me, but I don't know what. I can certainly get the job done. I wish it was a little bit crisper, so I'll say that it's got some mildly unpleasant deficiencies in that I've got to do some compensating for the lack of immediate response, but sensitivity wise and the whole schmeer, it's a pretty good airplane.

Pilot A: 4 (K = .45)

The airplane does what you tell it, but it almost seems like there's an additional mode snuck in on top of it sometimes. It will get a quirk in the response and there's a modest amount of lag in the onset, but it's not a major problem. It's just a little difficult to be as precise as you'd like to be with the configuration; however, I can get the job done certainly, but there's something in there that's getting to me. I can get the desired performance, but I've got to work.

HF121

Pilot A: 6 (K = .45)	There is a perceptible lag in the lateral response on this configuration. There seems to also be another mode in there. I get almost a secondary response sometime. The primary problem is that with the lag in getting the attitude, I have to over correct and therefore, I'm always using a larger bank change than I think I need initially. Instead of being able to get away with corrections on the order of 10°, I'm usually using 20°, so I'm almost at a PIO situation; fairly large corrections. I can fly, but I don't have any great difficulty in controlling it. I have a problem with precision control. It can't be done. The deficiencies certainly warrant an improvement. I can get what I would consider adequate performance, but it does take a lot of pilot compensation. If you have a really tightly defined task, low altitude, hover control or something like that, it could get into the Cooper-Harper 7 area.
Pilot A: 4 (K = .45)	Fairly good configuration with a bit of delay in there. The delay comes across as a nuisance that I'm not real enthusiastic about, but it doesn't really impeed by ability to do anything except very, very, very tight tasks.
Pilot A: 5 (K = .45)	Sensitivity and rate seems good. You've got a distinct noticeable lag in the response which gets you immediately into an over correction situation. You can't make the small corrections immediately and you get into a wing rock, rocketing oscillation, constantly over correcting from one side to the other. It's not a PIO problem, it's just that in order to stop a drift, you put some in, then you put some more, you put some more and put some more then you got to leave it all out and it doesn't come out fast enough, so it's a definite nuisance. You can't get the desired performance certainly. You can get adequate performance. The airplane's just slow to respond. You don't have any controllability problems or any real PIO problems with it. It's definitely a very objectionable deficiency.

HF1T1

Pilot D: 6 (K = .6)

At times I felt like I was doing really well and other times I get into more trouble than the others. I had performance degradation that surprised me. In general, thought the airplane was controllable. I think I could get the job done, but I didn't think it was satisfactory without improvement and I don't think I was achieving desired performance, so we're talking about adequate performance. There was something about it I didn't like and that's for the translation, if I could stabilize the airplane, if I didn't have any of these wind shears and was just trying to stabilize in the hover, I could get it stabilized. Trying to contend with the disturbances and principally the wind shear, left something to be desired. I do find as I said, deteriation right at the end of the third approach. It seemed like I got hit by more gust, more wind shears and I had definitely less capability to stop and I was tending to over control.

Pilot B: 5 (K = .3)

It's a hard one to figure out. There's something I don't like about it and I'm not sure whether it is a differential in response as you move the stick outboard or whether there's a little more lag, or just what there is. I can't really figure out what's bothering me, but there's something I don't like about it.

Pilot A: 4 (K = .45)

The airplane seems quite loose. Not too many problems. Sensitivity/controllability what have you, are pretty good, almost a continual low amplitude, low frequency oscillation. It seems that the auto damping is down is what I perceive and I've gotta sort fight it a little bit to keep the wings level. So, you have to do something to fly the airplane. I'm not quite sure what it is, but I perceive it is an annoying deficiency.

Pilot A: 2 (K = .3) $Y_V = -.2$

I've got no qualms about that one at all. Super configuration.

HF1T2

Pilot A: 7 (K = .45)
I'm not real happy with that one. You got a perceptable lag. There's something that looks like a secondary response. You really got to be smooth on your inputs and you got to try to stay ahead of the airplane so you need extensive compensation. It requires improvement.

Pilot C: 7 (K = .45)
I got a bunch of response to the input that I had, it seemed to me like for a very small input and then I had to take it back out because it just began to build up exponentially, I felt not to a great degree, but it wasn't linear. This is very sensitive laterally. Without the gust, it's a little better. It is sensitive laterally, maybe too sensitive and probably would be sensitive to gust.

Pilot B: 6.5 (K = .45)
There's a big lag in there.... I find myself making an input-nothing happening and going into more input and then starting to do the bang-bang routine. Also, I find myself getting out of phase with it trying to hover precisely. It's very disturbing and because of the strange action laterally it feels like there is a giant disharmony in pitch.

Pilot A: 7 (K = .45) $Y_v = -.2$
Reasonable underlying dynamics with a distinct noticeable and objectionable lag in the response. Totally wipes out your ability to make small corrections. I even got a little hesitation on it. The performance is adequate at that level. We're somewhere in the 6 to 7 ballpark. I don't have a tendency to couple into it. I guess the deciding factor is going to be that in this case, I would say that that amount of lag definitely requires improvement. It could be somehow diasterous under certain conditions.

HF1T3

Pilot B: 4 (K = .6) — Maybe a slight difference in the lateral sensitivity. Hover response maybe slightly different.

Pilot A: 7 (K = .45) — OOOOH Help! I said the lag in the last configuration was noticeable, this would have to be very noticeable. Well definitely major deficiencies. I question controllability. I think I could land it in an absolute no wind situation. I'm not sure I could land it with any turbulence, cross wind or anything like that. Adequate performance was not attainable certainly. If my task is properly defined as trying to stay somewhere over the concrete and avoid sliding it, I would have to say that for that, I could back away from it and get high enough, controllability wouldn't be a question. If you play the game and say that well yeah, but you're operating in close proximity to the towers, platform ships and what have you, I would say that controllability is a question. It depends on how you define the task. I'll go into this in detail, but the 7, 8, 9, ratings are very, very task dependent. So, for the task you gave me, well I didn't crash it really. For anything that required a slightly tighter control, I think there would have been serious questions.

Pilot B: 5.5 (K = .45) — I don't like the lags in it, but I can come closer than I could with some of the other ones.

HF1T4

Pilot B: 7 (K = .3)

This one has someone down in the control room that's a little bit slow to answer when I holler at him. That delay is long enough for me to see it. I can easily get out of phase with it. I move it and I say wait a minute it's not going far enough or fast enough. I've got to use more control and I will start to over-control. I'm deliberately not over-controlling here, but it would be very easy to do. It wouldn't recover fast enough, from large changes here. I'm getting out of phase with it when I'm trying to really tie it down tight. I can't get it to where I want it. Not with that kind of lag.

Pilot A: 7 (K = .45)

Distinct, very objectionable lags, controllability is almost in question. At that altitude, I can avoid getting into major difficulties. If I got close to the ground, I would have serious questions about the controllability. I think if you try to get this thing down into a landing condition, it might possibly be an 8 where controllability is a distinct problem.

LF121

Pilot C: 4 (K = .45)	Part of the reasoning is that it handled the gust very nicely. It handled large corrections nicely in and out. The only thing that I did not like here again, was the fact that once I got it into the hover and got it stabilized, I still had to continue to fly the machine. I couldn't take my hands off.
Pilot A: 3 (K = .45)	It flies good like an airplane should. Nice. That's a pretty good configuration. I think I perceive a small lag in rate onset, but the dynamics are very good, stable, well damped, I get exactly the response I call for and with reasonable repeatability. I would say even a little pilot compensation is required for desired performance. I can stay very close to my desired spot.
Pilot A: 3 (K = .45)	Nothing dynamically wrong with that configuration. I think I could use just a shade more sensitivity on that, not a whole lot. I can certainly get the job done. With maybe a little more sensitivity I'd have to go with a 2.

LF123

Pilot A: 3 (K = .45)	I sort of like it. It goes where I want it to go. Maybe there's a problem with the sensitivity. There's something in there that's a minor nuisance. Maybe right around neutral. It's giving me a little bit of problem on very, very minor corrections, but it's very pleasant to fly. It's predictable, it goes where I want it to go. It's very pleasant to fly.
Pilot A: 2 (K = .45)	I think it goes where I want to. I don't notice anything unusual in view of how well that performs. I'm not having any trouble establishing wings level, it does go where I want to point it. Sensitivity is good.

LF125

Pilot A: 4 (K = .45)	You got something in there I'm not real enthusiastic for. I don't know if I got enough bank angle at full deflection. I can stay pretty close to where I want to, but there's still something in there that's annoying me. So, I'll say there's moderate pilot compensation.
Pilot A: 3 (K = .45)	I've got adequate response for large inputs if I try to couple fairly large maneuvers in there and response comes from the large stick inputs, at a reasonable rate. I don't seem to have as much response or sensitivity for small inputs, so for small corrections, I seem to have to use more stick than I think I ought to and I wind up correcting twice more or less. I'm not quite sure what that translates to. Precision is good in that I can get there and hold it and I can get back to wings level and things like that. It's precise in as far as holding an attitude, but I am having to put in a little bit more stick. Sometimes I put it in and I have to put a little bit more, so I guess the sensitivity.... I sense a sensitivity change for small inputs. It certainly goes where I point it, but I do have to compensate for it and I'm trying to decide if I have to compensate, if it warrants improvement, or if it's something I'll live with. I'm really not having a great deal of problem with it, it's just something I could adapt to. There is something in there that I don't like as far as the sensitivity goes. It's something I could certainly live with.

LF127

Pilot A: 4 (K = .45) That was a nuisance. It feels sort of like there's occasionally getting some kind of secondary response in there. I'm getting what I ask for - almost a two stage response. It's controllable, goes where I want. Rate build-up might be a bit slow. I could handle that with a little more sensitivity. It does what I want it to do, I'm not really having any major problems with it, but it does require some compensation.

Pilot C: 8 (K = .45) I don't like that one at all. That's too much work. The thing that I didn't like was that it took a lot of input to get a motion started and then slowing it down took some input and then once you got it reasonably sorted out, it would just sit there and wander and I'm not sure whether those were pilot inputs or what, but I couldn't get the system really stabilized and I was just continually having to fly the machine. It took a lot of pilot attention just to fly the machine and we don't want that.

Pilot A: 7 (K = .45) I no longer really feel I have enough control to get the job done. Just comes across as both rate of onset and also, the sensitivity in as far as bank angle per degree stick, so I think I'm down in gain and frequency both. I would have to say that for this task, I do not believe I am getting adequate performance. Controllability is not in question.

LF121*

Pilot D:
3
(K = .6)

That seemed to be getting closer to something that I think is satisfactory. No problems with the feel system. The attitude response was smooth, the initial response was okay and that was predictable. The capability was okay, I thought the initial response was a little bit quick. I was able to contend with what seems like a large lateral upset in terms of the wind and I was able to discern the existence of it which says that I was able to control the lateral. Flight path attitude trade-off; if you mean by that how much attitude I had to use to get the translation, I thought they were well matched. Height response; I paid a little more attention to the initial throttle setting and was able to stay around I think 75 feet, a little lower than I had been before. The gust disturbance seems of fairly large magnitude. I was able to get back and every time get over the line, so that in some way, I think the translation of the airplane is clearly controllable. I thought I could do the job and I felt like it was a smooth, reasonably precise airplane. So, I think it was satisfactory, the only complaints that I have is a little bit sensitive initially than I might like.

LF123*

Pilot D:
7
(K = .6)

It's very difficult to understand what's going on. It's a very strange airplane to fly. The first translation to the left and coming to a stop on the left edge of the runway was smooth and relatively predictable. (This was an early run with the partial objective of developing the task definition. The pilot first moved to the left side of the runway, with no wind, before completing the standard task.) I tended to stop earlier than I wanted to so that the bank angle seemed to be going in more discrete steps than I wanted. It was very rapid and stopped very rapidly, very quickly. Then, as I came back across and did the getting back to the right edge of the runway, I got into the gust. I would have increasing difficulty and it was very snappy when I would try to correct, and it really blows my mind with my visual scene here, but then I'd end up with an increasing steady state right stick requirement until it was surpassing my feeble right arm, and each time as I ended up roughly stabilized in over the line in the hover, I'd end up with really heavy lateral forces to the right, and the way we're doing the task, not changing the heading and so on, as we talked about, the airplane has deteriorated and was aggravating with a little sense of somebody else flying it on occasion. But getting to the rating, it was controllable. Attitude performance attainable and in a sense, I could - I thought I could - achieve the performance, but I sure had to work too hard to do it. But, I didn't think the compensation was tolerable in that sense that disconnection with the airplane, where you don't really correlate with what to do to get the job done, that was the disconcerting part. When I actually got stopped in the hover, on the second part of the lateral translation, I had that really heavy force, which is not acceptable. The initial one, I couldn't stabilize it in the lateral. It seemed very quick response with a funny sort of lateral trim problem interacting with attitude. If I had nothing else to do but just hover the airplane, as you give it to me, the initial conditions, and I stopped there and just hovered, I think I would say that I could do the job. But, the extraneous, what seemed like lateral trim, input build-up after a period of time made it unacceptable. So, I really have talked about the forces were a major problem near the end of the task. Sensitivity seemed overly sensitive in combination with that, which is a disconcerting combination. It

LF123*

moved very rapidly and I had to hold large forces, so it wasn't tuned properly. The attitude response, I didn't notice any tendency to oscillate, but these other factors dominated my problem. Flight path response, initially okay. I could get over to the left side, I tended not to be able to bleed off the bank angle and stop where I wanted, but that was okay, but it deteriorated going to the right side in the face of the wind shear. Although I didn't move as far as I have in some, I was more having a problem with the bank angle control and the extraneous trim that I was positioning. Height was not a problem. As I said in the hover, it would be a little better if you only hovered for a little while.

LF125*

Pilot D:
10
(K = .6)

That was a very strange airplane to fly. Controllability was a problem, especially on the third one. I just about lost control of the airplane. It seemed to start out alright, and then I was unable to get back over to the right and with increasing right stick, sliding to the left and the last of the three, I ended up just about sliding into the ground going left. The forces and displacements are very noticeable, once it got near the end of the task whether I was getting the wind from the right or whatever it was, I had large stick displacements and seemingly sluggish response. The attitude response initially seemed alright, but at the end I was really unable to increase the attitude in the face of sliding to the left and stop the slide, I didn't PIO, but controllability was a problem. Flight path response was not predictable, special inputs were; you use all the muscle you had to hold it over there. I got very confused between flight path and attitude; it seemed like things were changing very dramatically during the course of the task. Height response was diminished in that I felt myself up over a hundred feet and paying a lot of attention to everything. I felt the wind. I didn't feel any turbulence, but there must have been some very large wind effects, because I ended up sliding left across the runway while trying to go to the right. So both the translation and the hover problem, I could never get stabilized in the hover, although a couple of them I did get over to the left edge of the runway and stop it there. My ability to fly the task decreased as I went through the task and each time coming up to the right edge of the runway to try and stabilize I had great difficulty even staying in the right side of the runway, right half of the runway and the last one, I came perilously close to crashing, but I think the airplane is really not controllable. I could control the translation. Initially I could, but in the final, the last task I really was trying to hover and ended up translating it and unable to control the translation, so I think if I started out as we started the task and just do anything, it went along in the lateral axis stayed stable, but very disconcerting, very easy to get, it felt like you were horribly crash coordinated, although I wasn't, at one time I did inadvertently use the rudders. I wanted to turn to the right to see if I couldn't solve why I was getting the big lateral translation in almost the reversal, apparent reversal of the control pushing right and going left. I find that I push right and go left and I don't like, but that's like having a lot of adverse yaw with a high dihedral effect I guess, I just got disoriented flying the thing.

LF127*

Pilot D: 10 (K = .6)	I can track the center line for awhile anyway. Regardless of how it looks one way or the other, I'm starting to build-up a bias with less translation. Now I'm building in a lot of right stick, banking left, feeling very uncomfortable. Further right stick, banking left, going left, unflyable.

N2LAT

Pilot B: 6.5 (K = .3)	Pitch and yaw and height response all three reasonable. If all I want to do is hover it and nothing else, I can just sit there and not do anything, but if I want to change positions, the extreme overdamping is getting to me and I could go to lots and lots of lateral stick displacement with absolutely no increase in ro. Very high roll rates right around neutral, initial breakout, are unacceptable.
Pilot D: 5 (K = .3)	In general, it's a well behaved airplane except it's too quick. It's just too abrupt initially and it's doubly disconcerting because of the visual display. You really get yourself into a position where your trying to fly the airplane aggressively. The rapid movement for tiny inputs really slow my mind and visual mind, so that if I did consciously try to fly the airplane smoothly and I could achieve satisfactory performance, but in the face of the gust I couldn't always do that and I ended up with these very rapid, almost rachety type lateral responses which I didn't like, but I think it's controllable and I did think I could get the job done. It's not satisfactory because it's just too quick, too abrupt. So, it defifinitely should be improved and I don't think therefore, I'm gonna achieve a desirable performance, but I think all and all adequate performance and out of the gust environment, if you smooth yourself down a little bit, you could achieve desired performance. If I just had to hover without contending with those upsets, it would likely be a 4. You can fly smoothly and you get smooth performance. You can't fly smoothly when you have to contend with the gust.
Pilot B: 5 (K = .3)	Wow, a guy could make himself sick in here with that one. As far as getting the task done, it's so quick and positive that I could make instant corrections. However, I think it's way too quick. I'm being very careful not to over control here and I'm getting back into the very small bang, bang motion again, because I can't control it smoothly otherwise. The rapid bank angle; well the very, very sharp, almost instantaneous bank angle is bothering me.
Pilot B: 3.5 (K = .3) (No Wind)	I find that one quite comfortable. I don't know, still got a little bit of lag there and a little bit of jerkiness, but at the same time, it's very, very easy to do.

N2LAT

Pilot A: 4 (K = .3) — The airplane goes the way you want it to go, just sort of instant bank angle, which is a little disconcerting. Visual display just instantaneously almost goes to commanded bank angle, so I'll occasionally get a rachet in the display, but usually just a bang, it's there and it's a little disconcerting. I perceive nothing unusual in the dynamics outside the repetitive response. I would say that the repetitive of the response is annoying. In fact, it is moderately objective.

Pilot C: 5 (K = .3) — That one was responsive. It seemed heavily damped. I put something in and it would pop right back out. Maybe you put a control input in and then if you didn't hold it in, it would come right back to neutral. So, a lot of stability there I guess. It wasn't bad. It's a little sensitive just for the normal inputs I think with a 20 knot crosswind, ramped in like that, it handled it reasonably well. The thing that I didn't like was the normal sensitivity to the stick inputs. It would just sit there and if you made any kind of unusual movement at all, it was very responsive to that and maybe slightly too responsive.

Pilot A: 4 (K = .3) — You move bang-bang. The response is right there. There's no lags. It goes exactly where you want to. So, it's not a problem mating the airplane to what you want to, however, it is a very abrupt response. I think you'd get used to it but it would have to hedge on the ride qualities. It's got an annoying deficiency there and that abrupt response.

Pilot C: 4 (K = .3) — It's very responsive. It does what I want it to do. I put it someplace it stays there. I take it out, it comes out and once I get it set where I want, I take my hands off, I got a hands off hover capability. Itll stay there. The only thing that's maybe a little detrimental is it may be just slightly, ever so slightly, and I hesitate even to say this, sensitive, but not bad at all.

Pilot A: 4 (K = .3) — We're back to the very rapid rate onsets, which I object to because of the display problems. When it jumps around like that, you start getting vertigo, so the response is more rapid than I would like. It's too abrupt. No perceptible lags, no nuisance modes. It's controllable. It goes where I want it. However, I do object to the abruptness of the response, so it's got an annoying deficiency.

N2LAT

Pilot A: 4 (K = .3) — The only objection is repetitive response. You start to get the display problems and what have you. Very controllable, goes where you want it to go. Just gets there too quickly. So, it's not really a question of compensation, it's a question of a deficiency that is annoying in this case.

Pilot A: 5 (K = .3) — Overall, the response is just very, very rapid. Much more rapid than I would like to fly. That makes it sensitive to small inputs, so I had trouble making small corrections. Repetity to response is almost a vertigo into the simulator. Not real wild about the sensitivity. I find myself getting into an over-control situation because of the over-responsiveness. So, I'll have to give that moderately objectionable deficiencies.

Pilot B: 5 (K = .3) — At first it seemed very sensitive and as I got used to it of course, that went away a little bit. Very light and sensitive right around neutral with a very rapid force build-up as you go out beyond neutral very far. Not pleasant in that regard. I can release it and it will come rapidly back to wings level, but I'm afraid that's pretty jerky if your actually flying it that way and I found myself compensating considerably just to detune the system. In other words, to be very careful not to make much of an input.

Pilot B: 5 (K = .3) — It's not bad right around neutral, but when I get outside of neutral, a half an inch or so, it feels like the rate changes. In other words, the gains change. I don't know exactly how to explain it, but increases in lateral stick position do not give me a corresponding increase in roll rate or roll angle, so I'm having to compensate. Very, very small motion, it's no problem at all, but once I try to get out there and get a little bigger bank angle, a little faster roll rate, I run into a wall.

Pilot B: 5 (K = .3) — It's a little bit quick, sharp, large force build-up beyond some 10° of bank or so, trying to hold it on there. Compensating for a little bit of lag that doesn't seem to help out any.

N2LAT

Pilot A: 3 (K = .3)

The response is too rapid for my likes for the joint reason that I think it's unrealistically fast for flight and also, I get this minor case of vertigo with the display outside jumping up and down, but the response is quick and precise. I can put it exactly where I want to, and I don't have to pay a whole lot of attention to it. It's just very distracting with that high acceleration roll performance. I can certainly get the desired performance and I don't really have to compensate, although I would have to say that the display is a minor problem as far as I'm concerned and I think it's unrealistically fast for flight.

Pilot A: 3 (K = .3)

The problem here is the blindingly fast response given that vertigo inducing situation of the outside display flickering. On a couple runs ago, we flew one that had a very rapid onset, well a very rapid roll rate, but it seemed to be a slight softer onset. It appears quite harsh and you have to actually back away from your pilot inputs. The airplane follows the helm precisely, but too quickly and it would be very uncomfortable riding and I guess the big complaint I would have is it would probably be very bad ride quality. However, the airplane goes exactly where you want it to go. It just gets there too abruptly. Pilot compensation is required in that in order to keep the outside roll rate down, you got to sort of back away from your input, but that's about the only thing that you have to do.

Pilot A: 3 (K = .3)

No problems at all. The airplane quickly and precisely answers the helm. I'd say this one is down just slightly in response, sensitivity is down just a shade, so I'll say that I wish it was just a shade more response in there.

Pilot A: 3 (K = .3)

We're back to the very high rate configuration where when you bang your stick over, the airplane bangs over and the outside display goes bang, bang. It's a little disconcerting visually and it would probably be uncomfortable in flight, however, the airplane goes quickly and precisely where you point it with a minimum of delay. I think there is a modest amount of delay in that response. However, it certainly is no problem coping with it. My only objection to it is you got a possible ride quality type thing and certainly is a little disconcerting watching the horizon going around at discrete 15° jumps more or less. So, I can get desired performance when I put the stick over, the airplane goes you know, what can I say?

N2LAT

Pilot A: 3 (K = .3) We're back to the instant bank angle machine. No delays, certainly none that are perceptable. Sensitivity is fair. Rate onset is instantaneous, therefore, we get the flickering outside display, the vertigo inducing jumping in the horizon and the possibility of a very, very poor ride. However, the airplane instantly goes where you point it. It means controllability is excellent, hedging of course as usual, the ride qualities.

Pilot A: 3 (K = .3) No problem with sensitivity. No noticeable lags, delays and what have you. The problem is the abruptness of the response which leads to the display problem and the vertigo problem and everything associated with it. I can make the airplane to do precisely what I want. It's very precise. It's just a little bit too crisp. You don't couple into it or anything else. It's just I believe it would be an awfully uncomfortable ride in a flight vehicle and you might possible get into some PIO just because you're getting bounced around, but you can certainly, precisely control it in the simulator. Hedging, of course, the ride quality.

Pilot A: 5 (K = .3) Am making a very small input so I can get pretty much the performance I desired. There's some lag in there or whatever. It's giving me a little problem with position control. Can't really put my finger on it.

Pilot A: 4 (K = .3) The big problem here is the very, very rapid rate. We start getting a display jumping and display flicker. It's instant bank angle and once you adapt to the sensitivity in terms of bank angle per stick deflection, you tend to go to a bang-bang control mode where you pause a second to mentally figure out exactly what you need to put the stick there and just relax, because the airplane will do it. It would be an uncomfortable ride and you have to adapt. I found myself adapting slightly different than normal piloting strategy on it. I can certainly make the small corrections I want to make. I don't like having to go to that bang-bang control mode, on the other hand, I don't really think I do, I just found myself doing it. I can get the desired performance, my two hedges are that I found myself doing something I wouldn't normally do with an airplane going to a bang-bang control and also I hedged the ride quality.

N2LAT

Pilot A: 4 (K = .3)

Nice crisp response. Sensitivity is good, I guess I see a barely preceptible lag in the response. Very controllable, very predictible, it gets the job done. Might be a shade harsh on the ride qualities. Got a few oscillations going on the first flight, but I really had to force that, so I wouldn't call it PIO problems. I like the sensitivity. The rate may be just a shade on the high side, but all told, not a horrible configuration.

Pilot A: 5 (K = .3)

That one's a little puzzling. I'm getting occasional oscillation on the inputs - small inputs and occasionally on large inputs. I don't know if I'm inducing ot or if there is an oscillatory movement. Dynamics is a distinct nuisance. The airplane seems relatively sensitive. The rate is a bit too high for flight. I think I'd have to hedge on the ride quality of the way the airplane gives you that instant bank angle, but it's definitely got - I'm definitely having some problems getting the oscillations out, it's a combination of high sensitivity and small lag or what. Whatever, the airplane's oscillation prone, not PIO prone. You don't tend to couple into it, it's just you get almost like an underdamp response sometimes. As I said before, I don't know if I'm inducing it or if it's something in the dynamics. Because of that, I can't make the fine corrections that I'd like to make, so I guess I'd have to say I can't get the desired performance. I can certainly get adequate performance and it's just a nuisance in there.

Pilot A: 3 (K - .3) $Y_V = -.2$

Another good configuration; however, the rate is a shade too high. I think you'd have a ride quality problem in flight.

Pilot A: 4 (K = .3)

We're back to the very, very brisk dynamics that would be a distinct nuisance in flight from a ride quality point of view, definitely. I can make small corrections. I don't know, there may be a little bit of a lag in there. If there is, it's not enough to be anything more than a distraction. My only major - my major complaint with the configuration is the abruptness of the response. It does cause me to change my pilot strategy, because I go to this bang-bang operation which I said before, I'm not particularly wild about, but I can get the performance I think I want out of the vehicle, but I'm not wild about it.

HF211

Pilot A: 6 (K = .3) $Y_v = -.2$

The problem here is just the response is down. Sensitivity primarily, although it's a combination of oversensitivity with the lower rate system it seems like, so you have to stay on top of it and even then, just because you have to move the stick so far in order to get the response, you always will be a little bit behind the requirements generated by the external disturbance. The airplane is controllable. You've got enough control, you just can't get it very rapidly. It feels like you're flying a very big airplane. Deficiencies warrant improvement, certainly. I'm going to have to say that adequate performance is obtainable, but it's borderline. If the response was down much more, we'd be in the 7 or 8 ballpark.

Pilot A: 5 (K = .3) $Y_v = -.2$

It seems to me that we've got two problems. One, the sensitivity is down in so far as absolute bank angle is concerned, and two, the response rate is down. The airplane is sluggish and doesn't have a hell of a lot there in the first place. I cannot get the desired performance, because it just takes too long to stop the drift and such like things I'm going bang/bang. I go to full input, then neutral, then full input the other way. I don't really have the tendency to couple into it or get into a controllability questions, things just don't happen quick enough. I don't perceive any lags in the responses, just a rate problem so, adequate performance I think is obtainable. I think you'd have a problem at low altitude precision hoover, but I don't have any problems staying somewhere in the ballpark with it. Adequate performance is obtainable, but you have to stay on top of the machine. You can't get very far behind it.

Pilot A: 6 (K = .3) $Y_v = -.2$

The only problem with this configuration is it's too sluggish. Once you get everything together and the wind averages out and what have you, boy it stabilized as a rock. On a lot of tasks that would be quite appropriate for, however, there's no such thing as a small correction with this configuration by the time the airplane gets it in, you no longer need a small one, you need a large one, so it's a continual series of fairly large amplitude maneuvers to make a correction. We got a problem with not having nearly enough response. It's way too sluggish for a tactical airplane that would be exposed to a gusty environment. I can do this job, let's put it that way. I can do the job we're assigned here. I don't like it; however, if

HF211

you want to carry this down to a lower task, I don't think you've got the roll performance you need, so I'm going to have to say that it does have major deficiencies. For the task we're assigned here, the maintain station keeping at altitude. I certainly can't do it as precisely as I want to, however, I can do what I consider an adequate job. If we go down to the in close to the surface landing type task, I've got a question in my mind if you have sufficient control, for maneuvering and close to the ground in a gusty environment, so there is a question that down close to the ground or in close proximity to obstacle or something like this, it would definitely be a Level 3 airplane.

Pilot A: 6 ($K = .3$) $Y_v = -.2$ — Major problem with the configuration is it is just too sluggish. I don't have the tendency to get trapped into this very large bank angle and not be able to get it out in time phenomenon. Although the airplane is way too sluggish, with going in and coming out, I don't really have the controllability question I had earlier on some of those. I can get the job done. I don't drift all the way across the runway. I don't have the controllability problem. I guess I'll have to put it in the bottom of Level 2.

Pilot A: 6 ($K = .3$) — We're back to a sluggish configuration. It takes a long time to react to control inputs. Therefore, I can no longer make the small corrections that I would prefer to make and on top of that, I'm seeming to be having more problems with the configuration than I think I should. In other words, I'm oscillating considerably in position. I'm running a right to left much more than I should, not just in bank angle, I'm actually sliding sideways more than I should. I'm working harder than I should.

HF212

Pilot A: 3 (K = .3) $Y_V = -.2$	No particular problem. The response is down a bit, Sensitivity is down. On the other hand, it's a very, very precise airplane and no lags that I perceive, so, therefore, I would say that I'm using perhaps more stick than I've averaged on some of the other configurations, but the aircraft response to the input is quick and is reasonably rapid, rapid enough and precise. I guess I wish it had just a little bit more sensitivity, but I certainly have no controllability problems. I can't really say there are any problems at all.
Pilot A: 3 (K = .3) $Y_V = -.2$	Configuration is quite pleasant to fly. There may be a small lag or maybe it's just a soft response starting up. I guess the only problem I have with it, is I guess I wish it just a little bit crisper. In other words, I think it could be just a shade more sensitive to control inputs. I have no problem at all making it do exactly what I want it to, so it's definitely Level 1. If it had a shade more sensitivity, it might have gone to a 2.
Pilot A: 5 (K = .3) $Y_V = -.2$	It is a bit sluggish, therefore, as I said before, when you get into these configurations, there is no such thing as a small correction, which means I can't get the precise performance I would like to get out of it. I have to accept a little bit more oscillation than I would consider desirable, so I'm in the category of adequate performance.
Pilot A: 2 (K = .3)	I've got no major objections to the configuration at all. Quick, precise, does what I want it to do with a minimum objection.

HF213

Pilot A: 4 (K = .3) $Y_v = -.2$

Sensitivity is alright, but the rate of onset is down, therefore, the airplane comes across as being a little bit sluggish in a roll and it's an annoyance, certainly, but wish it was better. I could live with it. The airplane is precise. I can get exactly what I want, I just wish I could get it just a little bit quicker. However, I can control it, I wouldn't have any qualms about handling the airplane in a cross wind or anything else. So, I'm going to say that yeah, I can get my desired performance, but I have to push for it.

Pilot A: 3 (K = .3) $Y_v = -.2$

Airplane does what I want it to do with a minimum of grips.

Pilot A: 3 (K = .3) $Y_v = -.2$

The dynamics are basically pretty good, but it seems to ignore small high frequency inputs. I have a little bit of a problem making very precise small corrections. However, I can certainly get the job done. No major problems at all. It's got what I call some nuisance modes in there, so it's got some deficiencies. I'm trying to split the difference between mildy unpleasant to annoying here. Well, let's go on the basis of compensation. I do have to work to get the small corrections in, but I don't have to do a hell of a lot to get what I want out of the configuration.

Pilot A: 3 (K = .3)

All told, I like it. I might notice a little hesitation in the response on occasion. I don't think it's quite as clean a performance as I have seen.

<u>HF214</u>

Pilot B: 3.5 (K = .3)	I find that one reasonably comfortable.
Pilot A: 3 (K = .3)	That's pretty good. I don't have any problems with that one. The rate onsets about what I like. Sensitivity is good. I notice nothing perceptable in the way of control lags or secondary responses. I have a little problem with very small inputs, so I'll say it's got some mildly unpleasant deficiencies and maybe it's just the way I'm doing it.

HF215

Pilot A: 3 (K = .3) The airplanes goes where you point it. I don't notice any unusual characteristics. Response seems down which means it's not as abrupt and it feels like I'm getting more bank angle per unit stick. So, as far as the response to controls, as far as I'm concerned, it's pretty close to optimum. The dynamics aren't that shabby either. I can make the airplane go where I want it to, doesn't seem to have any lags, doesn't seem to have any bad damping characteristics, nothing else. Turn the wind off, 2.

Pilot C: 5 (K = .3) A large input over my spot, correct, stop, level the wings. Go forward small tiny corrections. It responded nicely to my inputs. The input stayed in there until I took them out. The only thing I didn't like is that it did not hold the fine once I put it there and it had a tendency to drift which required my continued -- for minor corrections - although I suppose if you let it go it really wouldn't have mattered. But it just didn't stay for fine corrections. It had a tendency to drift

Pilot B: 4.5 (K = .3) It's nice and smooth around neutral and so forth. I still get that rapid force build-up as I go out laterally in order to get anything to happen. I don't much care for that.

HF126

Pilot B: 4 (K = .3)	It feels much more comfortable. I don't know what, I can't honestly tell you why. It still has the high force build-up as you go out in bank angle, but everything else in between seems to be smoother and more responsive. It's much more comfortable.
Pilot A: 3 (K = .3)	Sensitivity is good, gain is good. I got good control feel and the airplane does go where I want it to go. I get the feeling it may be a very small lag in there. Rate build-up is good and appropriate to the task. I feel I've got good control over it. However, there is something in there that I'm not really sure what it is that bothers me a little bit; however, I can do the task. I don't really feel I get any problems close to the ground.

HF217

Pilot A: 3 (K = .3)	The dynamics are quite good, it's predictable. It goes where you want to. It seems I see a little bit of a second response. It's almost like there's an under damped mode in there someplace. I can't really sort it out. I don't have any problems making the airplane go where I want to but there's something in there that's getting to me. I can sure make it do what I want to but it's got something I don't like.
Pilot C: 5 (K = .3)	It's responsive to my inputs, I easily corrected the gust, wasn't over responsive. I felt like I was in full control and if I'm gonna put this thing down in 200 foot tall pine trees, which I've done many times, it's reasonable. Of the ones that I've seen so far. Well, what I saw was for small corrections and easy corrections it was reasonable, when I made an input I got what I was after. If I made large corrections it took a little more of an input than what I am used to but I don't think you are going to be horsing around like that.

HF224

Pilot B: 5 (K = .3)	The thing over corrected and it's cominq back and I can't stop that. It's a lot more comfortable. You really got some sudden changes here, but I just, as long as I don't move it much, it's alright. It's like a little bit of large motion in it and you tend to over correct back the other way.
Pilot A: 7 (K = .3)	Yes I could get into trouble with this one, couldn't I? That one comes close to being a little bit under-damped. I've got almost a continual oscillation. I think there's some lags in the response. I can easily couple into the motion. I got into a lateral PIO there for a few seconds. I lost a lot of altitude. I don't like that one worth a darn. That does require improvement if you get close to the ground.
Pilot A: 8 (K = .3)	We've got very, very PIO prone configuration, lots of lag, no fun to fly at all. I think this would be potentially disasterous. Got at least one crash out of it. Controllability is definitely a question. You have to back away from the task, because as soon as you go to a high gain activity, you couple in and get out of phase and it's bang-bang, back to back 180° rolls and the whole smear. Major deficiencies definitely. Pilot compensation is required for control, but I guess I wouldn't say it's intense as long as I remember to keep it slow. I can almost do the job.

HF225

Pilot A: 7 (K = .3)	My perception is that damping is down, but what I think it is, is you've got another damped mode in there someplace. I think that if I was at a lower altitude, I could couple into that one quite easily and get into a lateral PIO. I am noticing in at least one oscillation sometimes two oscillation on every stick input. I don't like it, deficiencies do warrant an improvement.
Pilot C: 7 (K = .3)	I don't like this one at all. It has a tendency to PIO. Any large movements manifest themselves with overshoots, laterally, both with and without the gusts. It just sat there and you are just moving that stick all day long and you don't need it.
Pilot B: 8 (K = .3)	This thing has a tendency to rebound each time I roll, put the stick position in and it goes over and bounces back. Well as you can see, I get out of phase with it a little bit and start oscillating back and forth and I'm not doing that deliberately.

HF226

Pilot B: 5.5 (K = .3) All I wanted to do is just hover, not make any big motions here. It would be alright, but as soon as I start to make motion laterally, then I discover that the thing is much too sensitive and it seems to be very nice just right around neutral and then it seems to gain response very, very quickly and I wind up oscillating a little bit. It's not comfortable.

Pilot A: 6 (K = .3) That one has still got a fairly sensitive response when it takes off, so I got to try and stay up with it and I think there's some kind of lag in it. I find out what I'm noticing most is when I put a control input in, I get a rebound, it's over to some angle, comes back and sits there and oscillates there a little bit and I think I could couple into; the fact that I did couple into it a couple times and I was never really sure if the airplane was doing its own thing or if I was driving it. I think I can get into a PIO on this one in a hurry. I'm never really sure if the airplane is doing something or if I'm doing something. I got to wait in order for it to settle down before I can make a correction. I could get into a PIO, but I'm sure the wind wasn't inducive, but it was me. So, I gues as far as I'm concerned, it has major deficiencies. I could stay somewhere in the vicinity of what I wanted. I can stay about where I want to, but I really got to stay on top of it. I think if I got close proximity to the ground, I'd have to go a 7.

Pilot A: 6 (K = .3) I don't think I like it very much. I can't notice any real lags in response but what I do notice mostly and object to is a secondary response. It seems poorly damped. I don't know if it's the primary or if there's another mode in there that I get some oscillation out of, so therefore, when I start getting into an activity where I'm pacing it with a stick, I never really know where the airplane is at, how far it is behind my input. The airplane is quite PIO prone. I have to make a conscious effort not to chase it to avoid a PIO. If I keep my control inputs down, I can do a reasonable job. The problem with that is, that I can get what I consider to be adequate performance, as long as I really stay on top of it. The airplane is quite PIO prone....the PIO sensitivity would be very bad on a PIO scale. In a high gain task like landing, I think I would be very seriously concerned about controllability.

HF227

Pilot A: 5 (K = .3)

The frequency content seems different. I don't think I'd couple into this one. I am getting some rebound. In other words, I put a step in and I'll get say 20° of mag then five of it will roll off. It's not, I don't perceive it as a damping phenomenon so much as something like rebound. A second stage in there. It's a nuisance, but it, I don't think I'd couple onto it, so I guess I'd have to say that's a moderately objectionable deficiency.

Pilot C: 6 (K = .3)

It is not very good in gusts. You put it in and it wants to come back out, and you put it in and it wants to come back out. However, out of gust it seems to be a little more sensitive than I prefer. But once you get it all sorted out, it will stay there or it did for me anyway in both cases. It is reasonable I guess.

Pilot B: 6 (K = .3)

I cannot find the bank angle I want. It goes further than I expect it to each time I move the stick. It's just not following me. There's too much lag. I'm not comfortable with it.

Pilot A: 6 (K = .3)

It's oscillatory with a lag; however, the response rate is down far enough on this one that I don't have the tendency to couple into it. Controllability is not a question in this case; however, adequate performance, I can get it. I'm not real wild about the oscillations in there. What we've got is objectionable, but tolerable dificiencies. I can get adequate performance, but not desired performance out of it.

Pilot A: 6 (K = .3) $Y_V = -.2$

The airplane has got some PIO tendencies. I think I could couple into it under some circumstances. It's not as easy as some I've seen to couple into, but PIO is definitely lurking around the corner. There's an oscillatory mode in there. Therefore, predictibility is non-existant. You put the stick over and you're never quite sure where it's going to stop. Everything is over and done with fairly rapidly and you can make a reasonable size correction, you can't make the small precision corrections you'd like to make. If you do, you're in a constantly oscillating situation, so I'll have to put it in the category of very objectionable, but tolerable deficiencies.

HF228

Pilot A: 8 (K = .3)	Wasn't a question of losing control, because there was a question of whether or not I ever had control. The problem is that you got a distinct two stage response that comes across as either being low in damping or having an overshoot, plus a roll back, plus a time delay. The pilot stands a very good chance of coupling into that particular combination and getting into a totally wild PIO situation. I didn't quite, but I could see very easily that I could have. I don't like this configuration worth a darn. It's definitely Level 3. Is controllability in question? Well, yeah, I guess it is in my mind. Controllability is in question.
Pilot A: 4 (K = .3)	I guess I see a little bit of secondary response here, like somewhat under damped. Get a little bit of oscillation sometimes on control input that's a minor nuisance.
Pilot A: 4 (K = .3)	Get what looks like a bit of a secondary response in there. Sensitivity is fairly good. Rate onset is fairly high. I don't think this is a real, real fast rate or maybe there's something else buried in there I'm almost but not quite having a display flicker problem out there. It's certainly controllable, however, there's that quirk. You put the stick over and the airplane banks over and seems to roll back about 20%, so it's got a quirk in there that I'm not real wild about, but I can certainly get the job done. It's just a matter of adapting a little bit to it. I'd have to say that I've got to compensate and remember that roll back's in there and I'm not real wild about the rate of onset and what have you. The problem as I say is a moderately objectionable or a minor deficiency. I think I can get the job done.
Pilot A: 6 (K = .3)	The airplane has got some PIO tendencies. It seems to be oscillatory with a bit of a lag. Therefore, I wind up on corrections usually oscillating my way through them and chasing it. However, I don't really tend to couple into it for large amplitude maneuvers. I can induce them, but I back right out. It's not a sustaining type phenomenon, but in the process of making corrections, I do get some oscillation in bank angle that I don't like, so I guess I'll have to put this in the category of moderately - well it's a very objectionable deficiency, but it's certainly tolerable. You can get adequate performance, but you can't make the desired small corrections.

HF229

Pilot A: 5 (K = .3) I'm not quite sure what it is I've got here. I think there's a bit of lag or a mid-frequency secondary response or something in there. What it translates to is, I can't all the time predict exactly what I want to get. Sometimes it comes across as a rebound, sometimes I don't quite get what I wanted. It depends a little bit on how I put the inputs in. The response is fairly brisk. Sensitivity is fair. The problem is predictibility, so it comes across to me as an objectionable deficiency.

Pilot A: 4 (K = .3) I got fair sensitivity, very rapid roll response, coupled with a modest transport lag. It's a little disconcerting sometimes to be able to spike the stick - then watch the airplane spike with a modest amount of delay in there. From the time you perceive that a correction is necessary and move the stick and the airplane gets there, that amount of time is appropriate to be able to make the desired small corrections. However, what you've got is a lag followed by a fairly hefty roll acceleration. As long as you put the stick in the right place, in the first place, you're alright. You make the desired corrections, but I don't like it. I will put it in the category of minor, but annoying deficiencies, because I do have to compensate a little bit and be right in the first place. However, I can get the desired performance.

Pilot A: 3 (K = .3) That's a pretty good configuration. Also, I can notice minor hesitation in the onset, but the combination of sensitivity and rate and everything else makes it a minor nuisance. I can get the job done with a normal amount of compensation. It's a quirk, I don't like about it, but all told, it's pretty good configuration.

HF220

Pilot A: 4 (K = .3)

The problem is that there seems to be something else in there other than the basic airplane. To a moderate large input, I get the bank angle, and then I get some roll back. I put the stick over and I might get my initial goal of 30° and then roll back to 20 say. Now, that can get to be a problem on some inputs, because about the time I perceive that it went further than I want to, I take the stick out, then it comes out, then I get into an oscillation situation. However, the majority of the time, the response is considerably more rapid than I am putting my average input in, so therefore, it sort of takes care of itself and I don't tend to couple into it. I can control the airplane, but I've got to remember what I'm doing, so I've got to definitely compensate for that additional mode in there. I think if the frequency of the whole thing was slowed down just a little bit to make it more compatible with the way I'm putting my inputs in, I think I could get into a PIO situation in a hurry. However, with this particular configuration, I don't have the PIO problem. I'm going to have to say though, that flying the airplane does require the pilot to remember what he's doing, make a conscious effort to let the airplane go ahead and roll back before he makes the second correction, so it requires somewhere between moderate and considerable pilot compensation, but I can certainly get the job done.

Pilot A: 8 (K = .3)

Well, that's what you might call a close encounter of the pilot induced kind, as you might notice from your strip charts. You've got the worse of several combinations. I see you've got that very rapid response coupled by a lag that is at least, for my pilot patterns, a PIO inducer. In other words, it is very easy for me to couple in and get 180° out of phase of the airplane. I can do it easily and repeatedly, rather amazing how easy it is to get into that. However, I can back out of it by just slowing down my inputs, because the airplane is so blindingly fast in response, you can damp the oscillation out by getting out of the loop. It's not a controllability problem that you wind up in some wierd attitude. It's when you go to a high gain task, it's quite easy to get out of phase of the airplane. However, because the thing's so blindingly fast, you can back out and make it do what you want to. It's rather an unusual situation. Well, I guess I'd have to say that at least for

HF220

my pilot technique for that configuration, there is the controllability question and hedge it by saying I can back out of it, but there are times you get into that situation in close to the ground, in close to an obstacle, where you can't back out of it right away. There you've got a controllability question hanging around the corner on this configuration that could prove disasterous under some circumstances. There's very definitely PIO problems.

Pilot A: 3 (K = .3) It's an alomst very good configuration, although I occasionally get some oscillation in the response, which takes it away from a 2. I'll have to say it's got some mildly unpleasant deficiencies.

HF221

Pilot A: 7 (K = .3)

I don't like it worth a darn. I'm not sure exactly what you've done there, but there is a mode that I got into at least twice, maybe three times, that is a moderate frequency - very sharp PIO mode, but it's a very sharp frequency band. It seems to be mostly for small inputs around neutral in the mid-frequency range I get an oscillation. Larger inputs it's okay. It seems to be maybe a slight delay and then an oscillation, and for very rapid inputs, it's okay because it sort of ignores them, but I find this mode in there that I can couple into and get into a PIO situation which I don't like. I'm not real wild about the overall response of the airplane and because of the problem of coupling into that PIO and I don't quite understand how I do it all the time, I'd have to say you've got major deficiencies in the airplane that under some circumstances at least, I can't get what I consider adequate performance, because I get into that oscillation mode.

Pilot A: 4 (K = .3)

Sensitivity is good. The response is quite brisk. I do sense that there's something in there that's interferring with reliability, to predict exactly where it's going to go, but I can't really sort it out with the small inputs I'm using. I'll say it's got a minor deficiency that I'm not real wild about. I can make it do what I want.

Pilot A: 2 (K = .3)

Everything sort of comes together on that one. It's a very pleasant configuration. It may be slightly brisk in a roll acceleration. You might get jostled around a little bit, but it does what you ask it to do quickly and precisely and with a minimum of fuss and bother.

Pilot A: 4 (K = .3)

I guess I perceive a bit of lag in the response on this. Rates - fair, sensitivity is fair. I can get the desired performance out of the machine, but I think you could get yourself into PIO situation occasionally with the vehicle. I'm not real wild about the dynamics; however, I can get the job done.

HF2T1

Pilot A: 3 (K = .3)	I think I could use a little bit more gain on that one; however, the response is quick. I think I would just like to see more bank angle per unit of stick deflection. Response is quick, but not too quick. Some mildly unpleasant deficiencies.
Pilot C: 5 (K = .3)	It is doing what you want it to do. I don't particularly care for it personally, that type of approach, I don't like the machine taking out something that I put in, but it is reasonable.
Pilot B: 4.5 (K = .3)	Around neutral and for small changes, it's quite comfortable, beyond that I get rapid stick force build-up and reduced response. It's comfortable as long as you don't try to do much with it.

HF2T2

Pilot B: 5 (K = .3) — I don't know what to say about that one. Some of it I like and some of it I don't. I get the impression that beyond about 10° of bank angle, maybe even 5°, I really get a large stick force build-up before any response that I get, but right around neutral, it's a little bit sensitive, but it's extremely damped. I don't have the tendency to oscillate that I had on some of the others. It's great in the absolute hover, but any maneuvering is bad. Can't predict it, it's just too big a change.

Pilot A: 2 (K = .3) — That's nice. That one's quite pleasant. It goes where I want it to go. It doesn't get there too rapidly, the gain seemed about right. I can find myself trying to make, well, easily making two axis corrections and not having an awful lot of difficulty with three axis simultaneous corrections, which means that workload is down in lateral axis. It's good, negligible deficiencies.

Pilot A: 3 (K = .3) — How sweet it is. The airplane might be a shade sensitive, but it certainly goes where you want it to go with a minimum of effort.

HF2T3

Pilot B: 5 (K = .3) I can do a pretty good job of hovering it, it responds smoothly around neutral, but at the same time, I wind up moving it in little steps. Don't quite understand what's going on, cause I really have to be careful when I move the stick, otherwise it tends to be moved in jerky steps.

Pilot A: 3 (K = .3) I think the airplane goes where I want it to go. It's not overly sensitive. The sensitivity is about what I like. It might be a little bit rapid, but not bad. I don't notice any gliches in the response, maybe there's a little secondary oscillation, but it might be just a display flickering on me. I can make the airplane do what I want to, I can make a multi-axis correction. Therefore, it's imminently controllable. I really don't see anything in there I object to horribly, so I have to say minimal pilot compensation is required.

HF2T4

Pilot B: 6.5 (K = .3) A little bit of wind I'll let it drift over the centerline. Don't want to drift that far, okay we'll come back. Quite controllable laterally. Within strictly in the hover, there is a limit to the bank angle. I'm not sure why it's being limited or if you want it to be limited. I can't get the bank angles I want. The thing just stops and of course, that would be an unacceptable operational condition.

Pilot A: 5 (K = .3) I now have got a lag in the response. The airplane is a little bit more sensitive than I think I would enjoy flying in flight. With the lag in the response, I think the lag and then the jump in the outside display is even more distracting in this case. I can get reasonably good performance as long as I remember to lean and stay backed away from it a little bit and not try and get too tense about staying right on top of the airplane. I don't see any PIO tendencies. I'm not sure I want to call that a desired performance. I can certainly get adequate performance out of it.

Pilot A: 5 (K = .3) My major perception there is a mid-size lag in the response. It presents a problem in responding to a rapidly changing situation in that I have to wind up over correcting. However, the overall response to the airplane is precise, so although I can't get the immediate precision control I want under all circumstances, I can certainly do the task adequately, so I'm going to back down to the moderate, or minor to moderately annoying deficiencies. I'm not real wild about the lag in the response. I'ts not so much really, a matter of pilot compensation, it's just I wind up having to use more control than I really like under some circumstances. You have to stay on top of it certainly.

Pilot A: 5 (K = .3) The major problem here is a noticeable lag in the response. Sensitivity is good, response may be a shade on the brisk side. The lag is enough that you notice it and don't have the problem we have with the other configuration of coupling into it. It forces you to change your pilot technique and since you can't get the very small corrections and instantaneously you certainly can't get what you would call desired performance for small corrections. You can certainly make the airplane go very rapidly where you want to, as long as you wait for that small onset, lag and onset.

HF2T4

Pilot A:
5
($K = .3$)
$Y_v = -.2$

A little puzzling. There's lag in the response. The rates of onset and what have you are fairly decent. Sensitivity is good. All told, I can make reasonably small corrections, but I'm forced to a difference mode of operation that I would prefer. I go to a bang-bang reaction, always reacting rather than a smooth continuous input. I'm just trying to more or less trial and error, hunt and peck on the amount of bank angle required. I'm forced to adapt to the airplane. I can't really get the precise small corrections I'd like, but I can get better performance out of it than I would have expected. I guess I'd have to say I can't get the immediate small corrections I want and I'm forced to change my strategy.

HF2T5

Pilot A: 6 (K = .3)

Sensitivity and such like things are pretty nice. You've got an imtermediate lag here. That means it's not on the nuisance category, but it's not a disaster either. Let me philosophize on that a bit; the lag that we have in this case, is perceptible, and forces the pilot to change his normal control strategy. If the lag was a slight bit less, I think there would be a PIO possibility of the pilot coupling into it by trying to obtain performance that he just couldn't get. In this case, it's blatantly obviously that the airplane is not going to respond instantaneously and the pilot just has to go to sort of a bang-bang strategy and when he wants to make a correction, he just trys something and waits a few seconds and sees if that was enough and if not, he puts it in again. So, he's in a bang-bang reaction, always reacting. Cut and fit, trial and error, whatever you want to call it. Certainly not the desired way to want to fly the airplane. I cannot get adequate performance, but I've got to think about it. I can't make the airplane react fast enough to instantaneously stop that drift, it's just not there. But, if I allow myself to loosen up on the task a little bit and say that stopping the drift instantaneously would be what I desired to do and stopping it not quite so instantaneously would be adequate. Well that's what I'm getting.

Pilot A: 6 (K = .3)

We've got a distinct noticeable lag. My impression is it's a little bit longer than would be necessary to couple into. In other words, I've got no problem at all determining it is there. There is a possibility that I could find myself in some task where I'd couple into it. However, I tried to get into it a couple times and I just back right out of it immediately, so there as no real problem. However, the lag is severe enough that you definitely can't get the response you want out of the airplane. The question in my mind is, can you get adequate response. Well, that's borderline. The possibility exists that if that lag got anymore perceptible, or slightly less perceptible, in other words, you could couple into it and get into a PIO situation.

HF2T6

Pilot A: 8 (K = .3)

There does exist a possibility coupling into this one, it's fairly brisk response with a lag and I think a pilot could very easily get himself coupled into it, and so borderline lose control of the airplane. I can't certainly, get the desired performance. I'm not even sure I can get adequate performance. Controllability begins to rear its ugly head a little bit here, because I think the possibility exist for a PIO. I think you've got a very distinctly PIO prone platform here.

Pilot A: 5 (K = .3)

Sensitivity is good. Response rate is okay, however, there is a lag in the response that interfers with reliability to precisely control the machine. It's not a big problem on the small inputs that I put in fairly slowly, but it does lead to a little bit of overshoot additional bank angle required, so I can't really get my desired performance; certainly get adequate performance. Again, with small inputs, it's hard to tell if I'd couple into it if I really got intense, but trying to maintain the altitude control sort of leads you to have to make small lateral corrections.

Pilot A: 5 (K = .3)

Well, that's interesting. I got about the same dynamics that as I had before, fairly very brisk response, high sensitivitity and the whole smear. However, there is a substantial time delay involved, so you don't really perceive it as that instant bank angle and to a certain extent, it's almost more flyable than the previous configuration. So, I would be tempted to say it's a better airplane, because the major way that comes across to me is, I don't, I'm not tempted to change my control strategy. It comes across as being a slightly softer response. On the other hand, I think you could quickly get into trouble with that much lag, so although it doesn't impact the way I fly the airplane like the previous configuration did, I'd have to hedge and say that in addition to the blinding fast response in getting coupled into it, it flickers and what have you, that would be uncomfortable in the real airplane. I think I'd have to say that you could probably get into trouble with this because of the delay involved.

HF2T7

Pilot A: 8 (K = .3) Controllability rears it's ugly head. I guess I'll have to say that I wasn't losing control and so therefore, it's not intense, it's borderline with that much lag, you could very rapidly get into a very bad PIO situation. I do have some question about the controllability of it.

Pilot A: 9 (K = .3) There is enough lag in that configuration to present a major problem. I question if I'm really in control of the vehicle at sometimes. I didn't crash. I didn't lose control, but I sure couldn't make it do what I wanted. Getting down close to the ground, I was in a continual large amplitude bank to bank oscillation. I have to stay on top of it and back away from it and lead all the inputs to avoid getting out of phase and into an oscillation. In close to the ground, I don't think I can even do that, so if the task was say a landing with any external disturbance, I think it would have been a 10. I don't think I could have landed the machine.

LF221

Pilot A:
3
(K = .3)

The lateral response is a little sharper. It goes where I want it to go. The gradient's good, gain is good. It might just be a little sharper in the response. I'm not quite sure. It seems like I've been having a little more trouble with it than I did the previous configuration. There's just something in there I can't put my finger on, but I'm not having any real trouble with it.

LF223

Pilot C: 8 (K = .3)	What I'm simulating in the rapid movement just for your info, I'll go ahead and talk my way through this one. What I've been doing is many times in Harriers, you'll come into a runway and you'll come over the middle and you have a wingman behind you and then you'll have to translate very rapidly from one side to the other. It's not uncommon to make a big input to get over there quickly, because he's probably minfuel, you're minfuel and he's got to have a place to land also. Then once I get past that, I'm trying to fine tune a spot to land and simulate coming down on a taxiway while my other three wingmen are landing behind me on the right, left, etc. I can't control it. It's totally unsafe, there's too much work.
Pilot A: 4 (K = .3)	There's something in there that I don't like. Some kind of additional response it seems like. I don't see any perceptible lags. I still think rate onset is a little rapid. I have some difficulty sorting out what it is there that I like. There is something in there that's a nuisance. It goes where I want it to, but I'm having more trouble with it than I think I should. Requires moderate pilot compensation and I'm not quite sure why.

LF225

Pilot A: 6 (K = .3)	Wow. Let's see, I hit the stops a couple times on that, so I'm not getting any the full response that I would like. Rate build-up was quick. I don't feel that I have enough control over it. I've got using too much stick to get the bank angle, bank angle was just really rapid. Might be a small lag in build-up, but I can't really tell. I get the feeling I'm not totally in control of the aircraft. To me, that it comes across as a very objectionable but tolerable deficiency. I can almost make it do what I want to, but I sure don't like it.

LF227

Pilot A: 6 (K = .3)

Just a little bit of rebound. I'm getting a little bit of rebound on the rapid input. It gets over to a bank angle and rolls out a little bit. It's not really in oscillation, cause it just goes over then comes back a little bit. It's a trifle unpredictable in that characteristic. I think there might be some lag in it. Also, the response is quite rapid when it comes on. I find myself working harder than I think I should. I think I could get in trouble with that if I got down to a low altitude and got into a real precision task.

LF221*

Pilot B: 5 (K = .3)	The roll force build-up is way too high, once you get past a little bit of roll and it tends to be, don't want to damp itself out very hard, but as far as actually maintaining the position, the response is good enough and it wants to hold itself there.

G120

Pilot A: 7 (K = .2)

Adequate performance is not attainable but controllability is not a factor. You just don't have any. Adequate performance is not attainable. It just is not there. You do not have sufficient gains or authority whatever you want to call it. Put it all the way over to the stop and continue to blow across the runway. However, because it is so unresponsive, it's not a matter of controllability becoming in question. You don't get into the PIO problems; loss of control. It just doesn't do what you want it to do. You're not going to get into serious loss of control problems, you just do not have sufficient control.

Pilot A: 7 (K = .2)

Your problem here is the gain is way down. You've got the worst of several thing going. I say it's controllable, but it's certainly not adequate.

G121

Pilot A: 4 (K = .2)	I think the underlying dynamics are good. It feels to me like the gain's down, I don't have the control response I've been seeing before by a long shot. I don't notice any lags. The airplane is a shade on the sluggish side, but the response comes on pretty quick. It just seems like I don't really have enough lateral control power and that if the wind was any stiffer, I'd run out. However, with the wind conditions that we've got, I've got adequate control margin. I wish it had more sensitivity. I can get the desired performance out of it, but I have to compensate.
Pilot B: 7 (K = .2)	That's lousy. Very, very big lag in it. Very sluggish. It takes lots of stick to roll it. I'm finding myself putting in big leads here trying to get it where I want it. I can't make it do what I want to do, because there's too much lag.
Pilot A: 7 (K = .2)	The response is down, sluggish and I'm not gonna feel I'm getting enough sensitivity. I can't do what I consider an adequate job. The controllability is not in question.
Pilot A: 7 (K = .2)	I just do not have sufficient lateral control to stop the drift. I've almost got enough, but not quite.

G123

Pilot A: 7 (K = .2)

It's pleasant as long as you don't have any wind on. I do not have enough response, so not only do I not have enough response, what I do have, I don't get fast enough. Therefore, I can no longer get adequate performance. There is a controllability problem because of a large lag.

Pilot A: 7 (K = .2)

I can almost stop the drift. I just have to put in more work than I really think is necessary, so that takes it out of the class of tolerable deficiencies. I have to give it a major deficiency even though I can't stop the drift. I guess it's semi-adequate, but at an intolerable pilot workload as far as I'm concerned.

G180

Pilot A: 2 (K = .8)	If anything, it's a shade too responsive laterally. I get a little bit of oscillation right around neutral. I don't know if it's stick sensitivity or the rate of bank angle onset. However, that's a very, very minor objection. The airplane follows quickly and precisely. As I said before, if anything it might be just a shade too rapid, but I can certainly make it go where I want and make it do what I want. I sort of like the configuration.
Pilot A: 4 (K = .8)	That's puzzling configuration. I don't quite know what's in there, but what comes across to me is a combination of a not very brisk airframe, with a very high stick sensitivity. I seem to be not in a PIO situation, but I'm constantly exciting a small wing rock type phenomenon. That's reasonably predictable and the sensitivity is reasonable, I can make it do pretty much what I want to, it's just got something in there that's annoying to me, so I have to say it's got a minor deficiency. You've got sufficient control authority of this configuration to get yourself in trouble if you really tried. Well, you can do that with anything, so I'll say as far as I'm concerned, I've got to compensate for the configuration, but I think I can get the job done.

G185

Pilot A:
4
(K = .8)

The problem here is we keep shifting sensitivity scales more or less. We've got very, very responsive airplane and like I said before, we may have too much attainable response for an attitude command system. However, in this case, it's combined with just a barely perceptible lag, so I never really got any oscillation problems or PIO, so I don't think there's anything lurking in the weeds. I can more or less quickly and precisely make the airplane go where I want, but I will say that it does have a bit too much attainable response and maybe either mid frequency effect or a bit of a lag or something in there that's an annoyance superimposed. I'll have to say I can get the desired performance if I compensate for it, but it's got some annoying deficiencies.

Pilot A:
4
(K = .8)

It's almost good. However, it's a totally different class of dynamics. Response is much more brisk. Sensitivity is considerably higher. I don't quite know what is annoying me about it. It might be a minor lag, or something at high frequency. I don't quite know. I have difficulty with small, very small corrections, because for very small stick inputs I guess I'm getting surprised a little bit about how much response I'm getting, so I'm having some problems around neutral. Maybe it's a slight response lag. Maybe it's just a pilot technique. Almost a pretty good airplane. It's in a minor but annoying category.

G188

Pilot A: 2 (K = .8) That's about what I want to see. Sensitivity is good, harmony is good, no perceptible lags, everything just sort of came together.

Pilot A: 2 (K = .8) I guess I'd say that I think in flight the sensitivity might be a little bit high. I think you'd be in a constant little bit of wing walk on touchdown, because of the sensitivity problem. However, as far as the simulator task goes, oh man, it's nice. Light control pressures and instantly answers the helm. No delays and what have you. It was very pleasant in the simulator. Hedging the possibility of being too sensitive in flight.

G181

Pilot A:
6
(K = .8)

You got a combination here which could present some problems under some conditions. You've got a very high bank angle capability, probably too high for an altitude control system, combined with some lags in response. On the first run on this one, I got myself into a fairly large amplitude PIO, bank to bank type thing for several oscillations. In close to the ground, it would have been utterly disasterous. Now, keeping in mind that you can get in trouble on any machine, on the other runs by backing away from it, I didn't particularly have that PIO problem. What I came across is noticing primarily the lag in response. So, making due allowance for the response character of the dynamics, you can compensate for the potential problem; however, it's lurking in the corner, so I'll have to say that adequate performance requires considerable pilot compensation. It certainly doesn't have a desired characteristic there. It might even have to say extensive pilot compensation. I does have the potential for disaster.

Pilot A:
5
(K = .8)

You've definitely got too much sensitivity in bank angle per stick deflection, for an attitude command system, I get the feeling I could do an aileron roll on this. This would be interesting if I stopped half way around. What that translates to is I have trouble making small corrections... Go over there and hold it there for a second, you're going to lose control of the vehicle. So, you read the warning, don't put stick over to side of cockpit and you'll be alright on not losing control. I think you've definitely got too much sensitivity. I do have trouble making the small corrections, however, I can get them done. I get what I consider adequate performance, but not the desired performance.

G110

Pilot A: 3 (K = 1.0)
There's something in here that bothers me a little bit. I don't know quite what it is. It goes where I want it to go. I don't have a whole lot of trouble with it. There's something in there that's annoying me.

Pilot A: 2 (K = 1.0)
Piece of cake. Gee, I like that. That HUD just went up to full brightness. (The HUD brightness increased during this particular run. HUD brightness was constant for all other runs.) I think that was distracting me a little bit during that run. It goes where I want it to go with a minimal of effort. It's absolutely a Level 1 airplane. I can't really put my finger on anything that I object to.

Pilot A: 3 (K = 1.0)
I don't have any trouble getting the job done and it does what I want it to do. It might be a little soft in there.

Pilot A: 2 (K = 1.0)
No problem with harmony. The airplane does what you tell it. Sensitivity is good and appropriate to the task. I have no problem making it do exactly what I want and I have to really look to even get a suspicion of the lag, so it doesn't really bother me at all.

G111

Pilot A: 6 (K = 1.0)	Just in precision, I sort of got to hunt and peck for it. The biggest problem I have is the inprecision in control. If that's something like time delay, I would say you're bordering on the ragged edge of a bad rating. It wouldn't have to get very much worse before I would have not very great difficulties with it. Adequate performance is I think attainable, but you got to really work for it.
Pilot A: 6 (K = 1.0)	We've got a very rapid response with - you know it's a rate, with a lag in there. Fairly high sensitivity, the combination makes the aircraft PIO prone. Because of the sensitivity, I find myself constantly over correcting small inputs. In other words, gettimg more response than I thought I was going to get and having to take it out, so I get into an oscillation. If you ever get into a large amplitude maneuver, you've got a very PIO prine configuration, because you can couple right into it immediately. I can get the job done as long as I'm very, very careful about what I'm doing. There is some controllability possibilities or some PIO possibilities lurking around the corner.

G112

Pilot B: 6 (K = 1.0)	I can't even figure that one out. I'm working hard trying to get things settled down. I haven't gotten what I would consider adequate performance out of it.
Pilot A: 8.5 (K = 1.0)	Very definitely PIO prone configuration. On the first run, I definitely got into a PIO that I had to just sort to put the stick back in center and politely take my hand off and wait for the thing to damp out, so controllability was very definitely a factor in terms of pilot compensation, yeah, I had to just get off the stick. It was necessary to retain control; however, I do not impact the ground. The second time at it, realizing that was coming, there were a couple times where I could see the PIO beginning to develop, but just by backing away from it in a hurry, I could avoid the control problem getting into a full blown PIO.
Pilot A: 8 (K = 1.0)	I've got major objections already. I'll make a couple comments on that. If I really back away from it and just consciously keep my inputs down, I can do a fair job. I got to stay on top of it, because it's very responsive and I think I can perceive some lags, so what I mean is I have to consciously sneak up on it as long as I keep my own inputs under control, I think I could get the job done. However, I also have some question about controllability on that one. If you start getting intense, you couple right into it and get into a PIO that you cannot get out of easily. So, compensation as far as I'm concerned is required for control. I've got to make a conscious effort to avoid rapid inputs. If I don't, I immediately get into a PIO that I really have trouble breaking.

G112

Pilot A:
7
(K = 1.0)

I got several things wrong with this configuration. You got way too much sensitivity for a bank angle command system. That combined with a lag, I think you could easily wind yourself up in a major problem of inadvertently putting in too much input, and winding up in some horrendous bank angle before you could get it out. The lag and the sensitivity and the response and everything else makes the aircraft PIO prone. In this case, I wasn't chasing a correction, it was just a constant low amplitude bank to bank oscillation, maybe 10° of bank. Very easy to fall right into. I think the sensitivity problem is extreme. It definitely requires improvement. That takes it out of the ballpark of the Level 2. I think puts it in Level 3. I'll say that you can get adequate performance as far as the task goes. However, I think you've got way too much sensitivity that could get you into a controllability problem in a hurry. Therefore, I think that sensitivity absolutely requires improvement.

<u>G113</u>

Pilot A: 7 (K = 1.0) Well if I back away from the control inputs, I don't get that horrendous PIO I started with. There is a bunch of things wrong with it. A very sharp response, laggy, inprecise. I can't put it where I want it exactly. I got to keep hunting for it, but of course it answers the helm, fairly briskly. I can do it, but I say it may be overly sensitive cause I sure got into a PIO there initially. But again, I can get what I would consider adequate performance, but I got to walk on tippy toes to do it. There could be task so defined as to excite that lateral PIO and controllability would distinctly come into question, but I didn't lose control and I could do the task.

Pilot B: 10 (K = 1.0) It's deceptive. If you don't move the controls very much, it's no problem, but boy once you get over a little bit of bank angle, it suddenly seems to just get all fuzzy. I could put the stick in the middle and stop it, but I can't control it.

APPENDIX C

PILOT DATA

Very briefly, the pilots' background were as follows:

Pilot A - Ex-military A-4 pilot, current in light aerobatic aircraft, some VSTOL and helicopter time. Current assignment as flying qualities engineer.

Pilot B - MCAIR test pilot, extensive AV-8 V/STOL experience.

Pilot C - MCAIR test pilot, extensive AV-8 V/STOL experience.

Pilot D - Calspan research and engineering pilot, very extensive variable stability CTOL and V/STOL aircraft experience.

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